The interrelationships between the macrobenthofauna and fish communities of the upper and middle Thames Estuary and some of its associated dock basins, tributaries and creeks

Bangura, Kolleh Alusine

The MACROBENTHOFAUNA AND FISH

THE INTERRELATIONSHIP BETWEEN ~~FISH~~ AND ~~MACROINVERTEBRATE FAUNA~~ OF THE UPPER AND MIDDLE THAMES ESTUARY AND ITS ASSOCIATED TRIBUTARIES, CREEKS AND DOCK BASINS

by

KOLLEH ALUSINE BANGURA

A thesis submitted in partial fulfilment of the requirements for the degree of

PhD

University of London

2005

Division of Life Sciences
School of Health and Life Sciences
Kings College London
Franklin – Wilkins Building
150 Stanford Street
Waterloo
London SE1 9NN
England – United Kingdom

UNIVERSITY OF LONDON

ABSTRACT

THE INTERRELATIONSHIP BETWEEN FISH AND MACROINVERTEBRATE FAUNA OF THE UPPER AND MIDDLE THAMES ESTUARY AND ITS ASSOCIATED TRIBUTARIES, CREEKS AND DOCK BASINS

by Kolleh Alusine Bangura

ABSTRACT

A study was carried out between April 2000 and October 2002 on the interrelationship between the macrobenthic and fish communities of the Thames Estuary and some of its associated tributaries, creeks and docks. Main river sites were selected in the upper and mid Thames Estuary. The Royal and East India Dock Basins, Dartford Creek, Chelsea, Deptford, Bow, Barking and Dartford Creeks, were selected to represent the docks, tributaries and creeks. Kick sampling, hand picking, wall scraping and core sampling were used to collect macrobenthofauna. Fish were collected along the foreshore with a 25m long fry seine net with 4mm knotless holes. The gut contents of 12 of the most abundant fishes were examined. Taxa lists, simple correspondence analysis (SCA), cluster analysis (CA), community structure metrics, relative percentages, diet overlap and selectivity indices were used to describe macrobenthic and fish communities and fish feeding habits. The study re-established that the Thames Estuary remains a Primary Nursery Area (PNA) for migratory fish species and that their species composition in the main river and Dartford Creek could be explained primarily by longitudinal changes in salinity and a marked seasonality. Broadly the connections and effects on each other of estuarine ichthyofauna are defined by their lifestyles, use of the estuary for breeding, feeding and distribution pattern of the species in space and time. Species composition transitions from one region to the next in the main river and Dartford Creek are gradual with species changes within families then whole families becoming less important until they are replaced by another species. Seasonality was related to the disappearance of fish fry in winter and spring spawning and upstream migration of fish fry. The creeks and docks had unique species assemblages but the *a priori* hypothesis that these habitats provided a winter refuge for fish fry was not sustained. The Queen Victoria Dock Basin provides a refuge for pollution sensitive species *Osmerus eperlanus* and *Atherina presbyter*. Analysis of fish gut contents and macrobenthofauna at the site and season of capture showed that fish diets fish species were closely related to the macrobenthofauna at the site of capture.

List of figures

List of Tables

Chapter 1

INTRODUCTION

1.1 An overview of previous fish, macroinvertebrate and gut content studies

The rapid increase in the population of London during the industrial revolution of the 19th century brought about deterioration in water quality of the Thames estuary and the progressive pollution gave rise to depauperate communities of fish and macroinvertebrates over much of the middle reaches of the estuary. Heavy organic pollution during this period led to anoxic conditions in which few fish and benthic macroinvertebrate species could survive. Even species known to have wide environmental tolerance were eliminated. The very tolerant eel (*Anguilla anguilla*) was also affected and although this species probably survived in small populations previously successful eel fisheries disappeared. The benthic invertebrate community of the middle reaches was reduced to a few species of oligochaete worms notably the tubificid worms. During the period of maximum pollution, (between 1850 and 1950 (Wood 1982) the estuary's fish species count fell to 5 (Huddart and Arthur, 1971a & c). The history of the fish population of the tidal Thames is well documented by Wheeler (1979) and the progressive recovery by Huddart and Arthur (1971a & c).

Much of the historic fish data for the Thames is based on fish surveys undertaken at the cooling water intake screens at power stations, Wheeler (1969a & b), Huddart and Arthur (1971a, b & c), Araujo (1992) and Araujo *et al* (1998). Studies on invertebrates are much less comprehensive, although studies by Andrews and Richards (1980) and Andrews (1984) confirmed that the main species present were tubificid worms which occurred in huge numbers. In recent years the power station fish sampling has been augmented by extensive surveys using a combination of shore seine and trawl netting (Colclough, 1992 & 2001; Colclough *et al* 1998; 1999; 2000 and 2001; Araujo *et al,* 1999). Invertebrate surveys have also been conducted with collections being made from the foreshores at low tide using a variety of techniques (Sedgwick and Arthur, 1976; Andrews, 1977 & 1984; Attrill *et al.*, 1996; Attrill, 1998; Attrill *et al.*1999). A common feature of these surveys is that they show an increasing diversity of both invertebrates and fish as the pollution load of the Thames Estuary declined.

The direct relationship between reduced organic pollution and the biological recovery of the Thames Estuary is overwhelming and indisputable (Huddart, 1971; Wheeler 1979; Sedgwick, 1978; Andrews, 1984; and Araujo *et al*, 1998 and 1999). The speed of recovery in the diversity of different animal groups has been variable - salmon for example were slow to recolonise even with restocking of the upper River Thames with juveniles. Other species have had to depend on natural recolonisation and this must depend on sources of sensitive species and their ability to re-enter the Thames estuary. The Thames estuary is not an isolated water body. It is in permanent landward contact with the main river and inflowing tributaries of the freshwater catchment. It is also in seaward contact with the open sea of the North Sea. Thus recolonisation of the freshwater species could occur from the riverine ecosystem above and marine species from the marine ecosystem below the estuary. Thus sources of most sensitive species would have been available to re-enter an improving estuarine habitat. For exclusively estuarine-dependent species, such as the smelt (*Osmerus eperlanus*) or the freshwater shrimp (*Gammarus zaddachi*), recolonisation may have been more difficult

Areas where species may be harboured and protected by conditions no longer available in the main estuary are known as refugia. Refugia may operate not only on a historic time-scale but they may also be important during intermittent periods of poor water quality. At present the Thames estuary, although generally of good water quality does undergo such intermittent periods of pollution (Woods, 1982 and Tinsley, 1998 in Attrill 1998 Ed). These episodes are particularly related to times of heavy rain-fall or periods of drought (Attrill *et al*. 1996 and Attrill & Power 2000) when polluted urban run off may enter the river as untreated storm water drainage and sewage via combined sewage outflows and cause periods of substantial deoxygenation. Another point of interest is that sheltered backwaters in an estuary may permit the survival of species in still or slow flowing water that would be washed away by the high flows of storm waters or even the fast-flowing ebb-tides of extreme tidal surges. This interesting area of investigation previously un-studied in the Thames estuary has been incorporated into the present study.

Previous studies on the Thames Estuary have largely been restricted to either fish or invertebrates. Recovery of fish and invertebrate populations are well documented but as conditions improve it is likely that the direct relationship between water quality and species survival will become less obvious and that other ecological factors will play a significant role. The standard view of estuarine community structure is that the primary determinants of species distribution are salinity followed by substrate and other predominant physical and chemical factors, Wheeler (1979), Blaber and Blaber (1980). These factors determine the theoretical range that a species may be found in. However, as species diversity increases, predation, competition and recruitment may heavily influence actual distribution patterns.

It is evident from the brief overview above that fish studies in the Thames Estuary started a long time ago but the more detailed and comprehensive descriptions of fish populations have only been made in the late 1960s when population levels in the river were critical. These works concentrated on the return of fish in the estuary and aspects such as the influence of organic (sewage) pollution in the tideway. After the recovery of the river from gross organic pollution and the advent of technology to accurately measure physicochemical variables in the 1980s onwards, focus on fish studies shifted towards investigations of the relationship between fish community structures and their physical and chemical environment. The major history of fish of the Thames Estuary is documented by Wheeler, (1969a & b); Huddart and Arthur, (1971a, b & c); Sedgwick and Arthur, (1976); Wood, (1980 & 1982); Thomas, (1998); Araujo (1992); Chen (1994); Colclough (1992 and 2001); Colclough *et al*,1998 and 1999; Araujo *et al* (1998 and 1999; Power *et al* 2000 and Colclough *et al* 2002). This study now reviews the main features of these historical studies briefly.

In April 1969 Wheeler (1969a & b) discussed the decline of fish during the 1950s and their subsequent revival during the 1960s. A survey of 1957/1958 did not find evidence of fish life apart from eels in the lower Thames Estuary, but by 1962 Wheeler (1969a) reported that fish were observed further downstream than for the previous five years. During 1968, marine and anadromous fishes penetrated upstream, the worst polluted reaches. In October the same year Wheeler (1969b) reiterated the fact that commercial fisheries of considerable economic value existed in the tidal reaches of the River Thames, until the middle of the nineteenth century. He stated that increasing pollution from industrial and domestic effluents led to their complete destruction and, in the twentieth century, to the virtual absence of a local fish fauna. Measures implemented during the time to control pollution had resulted in a partial chemical restoration of the River. Data collected by Wheeler, by sampling in the lower Thames, by collecting fish caught on the cooling-water intake screens of five electricity generating stations along the River, showed that fish were present in considerable numbers again. In the period from 28 September 1967 to 31 October 1968, forty-one species were taken. At the farthest upstream point, the majority of fish caught were freshwater species, while at the farthest downstream station, with one exception, only marine or euryhaline species were caught. This, and evidence that migratory fish had penetrated through the worst-polluted reaches into relatively clean water, was taken as an encouraging sign of the re-establishment of the fish fauna in the lower Thames.

Wood (1980 & 1982) made reference to river pollution of the Thames which reached its worst point in the 1850s in London and the lower reaches, which was relieved by construction of the northern and southern main sewers which discharged at Beckton and Crossness, respectively. However, pollution in the vicinities of the outfalls was heavy until treatment methods were improved at Crossness. Similarly, sewage treatment at Beckton was being improved by rebuilding. In the period between world wars 1 and2 there was no improvement maintained. Although there was still a pollution problem in the Thames at Barking, showed by relatively poor catches of fish, there was a good recovery in general in the lower Thames and a still greater improvement was forecasted when the rebuilding of Beckton works was to be completed in 1973/1974.

Huddart and Arthur (1971a) published another paper on the incidence of shrimps and whitebait in the Polluted Thames Estuary. This paper recorded the seasonal incidence of shrimps, sprats and herrings, the most abundant nektonic species, off West Thurrock Power Station in the Thames estuary during 1967/1970. It also dealt with their age classes and their diet. The object of monitoring the shrimp and fish fauna was to establish a quantitative base line against which the effects of future developments for the river such as the erection of a barrier were to be measured. It also served as an index to the effects of the strike of public employees of sewage plants on the river. Details were given of: methods, analysis of catch; shrimps (*Crangon vulgaris*) in the lower Thames Estuary; and fish recorded in some numbers in the Thames, in particular herring *(Clupea harengus)* and sprats (*Sprattus sprattus*).

Huddart and Arthur (1971b) reported the ecological importance of Lamprey and other teleosts fish other than whitebait in the polluted Thames Estuary. This was part 2 of the paper which appeared in International Journal of Environmental Studies, based on sampling off west Thurrock power station during 1967/1970. This paper gave results which were intended to serve as a baseline for measuring further changes in the fauna of the Thames Estuary arising from further possible industrial development and the erection of a barrier and included data on age classes and diet. In 1972, Arthur and Wheeler, the most noted fieldworkers in the fish fauna of the Thames Estuary during the time jointly published a letter documenting the improvement in the fish stocks in the Thames River since the authors report for the period 1967/1968. Mention was particularly made of catches of brown trout and sea trout.

Following these publications, Sedgwick and Arthur (1976) reported on the impact of a sewage strike on the fauna of the Thames Estuary which they described as a natural experiment. The effects of a strike of sewage-works employees in 1970 on the populations of fish and shrimps in the Thames estuary were described. The chemical condition of the estuary, the effects of weather changes, and the distribution of estuarine fauna were dealt with, and the changes observed resulting from the pollution were assessed by comparing data with faunal distributions from previous and subsequent years. The conclusions were that organic pollution had negative impact on estuarine biota.

In 1979, Wheeler (1979) summarised all previous works in a book entitled "The Tidal Thames: the history of a river and its fishes". In this text a history of the occurrence of fish in the tidal reaches of the Thames between Teddington and the North Sea was traced from the viewpoint of a naturalist at the British Museum. The account provided an interesting study of the changes occurring with the growth of London's population, accompanied by rapidly increasing pollution, and coupled with the restorative action undertaken between the wars and also more shortly before the time of publication, which had resulted in a considerable growth in fish populations during the 1970s. Records of fish catches obtained from numerous sources, many uncovered by careful historical research, were included, and the particular species of freshwater, estuarine, migratory and marine fishes which had been recorded were described. An assessment of the recent revival of fish populations and an indication of future prospects concluded their survey.

The 1980s were marked by further improvement in the ecology of the Thames Estuary. Andrews and Richards (1980) recorded 18 rare or little-known marine fishes in the Thames Estuary. The authors concluded that the presence of several species might have been due to dispersal by currents and tides of pelagic larval or post-larval stages. Many of the species reported must have originated in the Atlantic Ocean or the western Channel and probably passed through the Dover Straits

Thomas (1998) recorded a total of 52 species in surveys of 4 sites along the upper estuary, 1 site in the middle estuary and 3 sites in the outer estuary using seine netting in the upper Estuary, Power station screens in the middle estuary and trawling with beam 4 m trawl net in the outer estuary. Although Thomas (1998) used three different methods for sampling the three different ecological zones which in itself was a source for errors, he recorded eight species in the upper estuary; forty-two species in the middle estuary and twenty-five species in the outer estuary. The middle estuary fish species total was within the range of 42 - 56 found annually at the power station since the 'clean-up' of the late 1970s. In the upper estuary dace was the most abundant species. Dace of the year were caught at all four sites indicating that this species was able to successfully reproduce in the upper tideway. The total abundance of fish found in the mid-estuary was markedly lower than previous years. A decline in the number of sand gobies (*Pomatoschistus minutus*), herring (*Clupea herengus*), flounder (*Platychthys flesus*), smelt (*Osmerus eperlanus*) and sole (*Solea solea*) was detected. However, Thomas (1998) documented an increase in some species namely sea bass (*Dicentrarchus labrax*), whiting (*Merlangius merlangus*), Nilsson's pipefish (*Sygnathus rostellatus*), thick lipped mullet (*Crenimugil labrosus*) and transparent goby (*Aphia minuta*). Only flounder, smelt, sole and sprat (*Sprattus sprattus*) were found to be present throughout the year. A new species of fish for the Thames Estuary, the Solenette (*Buglossidium luteum*), was discovered during a routine survey at West Thurrock Power Station in December. In the outer estuary, flounder was most common in the surveys at Blythe Sands, whilst plaice (*Pleuronectes platessa*) was most common in the surveys at Southend. Reductions in salinity at Blythe Sands are thought to favour flounder at this site. Considerable fluctuations in species number and abundance were detected in the quarterly results, much of which could be accounted for by natural migration patterns. Plaice, pouting (*Trisopterus luscus*), flounder, sole, dab (*Limanda limanda*), whiting and pogge (*Agonus cataphractus*) were found to be present at one or more of the three sites throughout the twelve month sampling period.

In the 1990s more sophisticated methods of fishing and analytical models were introduced and postgraduate students became more involved in fish studies in the River Thames; studies now focusing on the ecology of individual or a few fish species.

Moreover, more sophisticated and reliable measurement of environmental variables had been developed by the National Rivers Authority (Now known as the Environment Agency).

Power *et al* (2000) reported on the temporal abundance patterns and growth of juvenile herring and sprat in the Middle Thames Estuary. Again, most herring *Clupea harengus* and sprat *Sprattus sprattus* (were sampled from West Thurrock power station intake screens, middle Thames estuary), between 1977 and 1992 were age-0 and followed regular patterns of seasonal occurrence. Juvenile herring entered the estuary in July, peaked in abundance November to March, and then declined. Juvenile sprat first appeared in September and peaked in abundance in January. Neither species was abundant in summer samples while in the estuary, herring and sprat increased in length an average of 4·0 and 0·33 cm respectively. Abundance of both species was reported to be significantly affected by temperature, temporal trend, shoaling behaviour and seasonal variables, and of herring by suspended solids. Interactions between environmental variables did not appear to influence the abundance of either species. The authors concluded in this study that as estuarine clupeids were influenced by a complex set of events within and outside the estuary, estuarine monitoring studies alone will not be sufficient for understanding the changes in estuarine fish communities resulting from future human activity.

Araujo *et al* (1998) also related fish species assemblages as indicators of water quality in the Middle Thames Estuary. Between February 1989 and August 1990, Araujo *et al* (1999) reported that the upper Thames estuary contained 23 species of fish. Fish numbers were higher and relatively constant in the uppermost part of the estuary. The number of species was augmented in summer from fresh water and from downstream, coinciding with high temperature, low flow and high salinity. The eight most abundant species contributed to 98·5% of the total number. Flounder *Pleuronectes flesus*, dace *Leuciscus leuciscus* and perch *Perca fluviatilis*, recruited from May to August, and common goby *Pomatoschistus microps*, roach *Rutilus rutilus* and chub *Leuciscus cephalus*, from August to November. The upper estuary (salinity 0·34-2·96 ppt) formed a species transition area between the freshwater but salinity-resistant roach, chub, and gudgeon *Gobio gobio* upstream, and the estuarine euryhaline common goby and flounder downstream. The three-spined stickleback *Gasterosteus aculeatus* and cyprinids were more abundant at upstream sites while perch was more abundant at downstream sites. High abundances of gudgeon, chub and roach were associated with high transparency and dissolved oxygen and low salinity, while high abundances of sea bass were associated with high salinity and low transparency. Dace and three-spined stickleback were associated with high dissolved oxygen and low pH, and common goby with high pH. Flounder showed no clear preferences.

Power *et al,* (2002) reported on the environmental influences on the long-term fluctuations in the abundance of gadoid species during estuarine residence. Samples were taken regularly from the intake screens of West Thurrock power station between January 1977 and November 1992. The dataset was used to describe the temporal patterns of abundance of juvenile herring and sprat and to examine physico-chemical factors influencing the abundance of Gadidae species (poor-cod, *Trisopterus minutus*; pouting, *Trisopterus luscus*; and whiting, *Merlanguis merlangius*) in the Thames estuary. Most sampled fish were age 0+ and followed a dominant pattern of seasonal occurrence. The authors used multiple regression analysis to model variations in sample abundance in relation to fluctuations in estuarine environmental variables, interactions between environmental variables and seasonal factors. They used model results to examine hypotheses concerning the relative importance of temperature, salinity, prey availability and seasonal factors as determinants of estuarine gadoid abundance. The authors made several conclusions: that temperature was the most important determinant of species sample abundance and negatively related to sample abundance in all cases. Salinity was a major determinant of pouting abundance and a minor determinant of whiting abundance, with seasonal factors significantly influencing the occurrence of all species. Crangon abundance was a minor determinant of whiting and poor cod abundance. Interactions between environmental variables played a minor role in determining the sample abundance of a single species, pouting; determinants of Gadidae species abundances in the Thames appear to be a complex mix of seasonal and environmental influences, with seasonal influences determining the dominant cyclical pattern and influences of temperature having the greatest effects on short-term variations in the pattern.

From the above reviews it is obvious that the study of the estuarine environment based on fish studies is a dynamic discipline with the studies and observations interlinking. The current management strategies of the estuary are based on observations and conclusions made in previous studies reviewed above. The current study aimed to contribute new knowledge and provoke new debates about the current macroinvertebrate and fish species assemblages in relation current habitats.

1.2 Research problem and justification

It is evident from the above historical reviews that little work has been carried out on the ecology of fish in other habitats associated with the Thames Estuary. The ecological importance of small rivers, creeks, lakes and docks have recently come into the spotlight because of recent European regulations and the Environment Agency's Local Diversity Action Plans which lead to the restoration of many polluted water ways in the United Kingdom. The reasons for the apparent neglect of the tributaries and dock basins by previous workers on the Thames Estuary are many fold:

(1) The activities of urbanisation have obliterated a lot of London's tributaries through the construction of industries and human settlements, roads, other developments above them, and their amalgamation into the drainage and sewage systems (Wood, 1982).

(2) The growing need for water extraction led to the impoundment of a lot of London's tributaries isolating parts of these water ways from the Thames Estuary (Wood, 1982).

(3) Difficulties in sampling these sites due to: a) lack of suitable foreshores as a result of the construction in the late 19th century flood defence walls around them, b) lack of low cost methods and c) difficulty of accessing sites (Colclough, 1992).

(4) Other relevant data e.g. physicochemical data are only easily obtainable in the Thames Estuary due to the point-in-time availability of these data in the Monitoring Department of the Environment Agency (Tinsley, 1998).

(5) Fish sampling using power station cooling water intake screens became very popular in the Thames Estuary e.g. Thomas (1998) Araujo *et al* (1992) and Araujo *et al.* 1998). This was a cheap and cost effective way of sampling fish not available in the associated waters.

(6) The potential ecological importance of the 250 ha of waters of the dock basins was not recognised until recently when the East India Dock Basin was integrated into the Lea Valley Ecological Park leading to its transformation into a bird sanctuary by the Lea Valley Park Authority. The current use of the Royal Dock Basins is for the

development of the Royal Docklands Business Park. The water areas are used principally for recreational activities, including sailing, canoeing windsurfing, rowing, jet skiing and water skiing.

Previous studies of the benthic macroinvertebrate fauna of the Thames Estuary have regarded the Creeks as parts of the main river. Sampling sites had been located on them as part of the surveys for the main river's macroinvertebrate species (e.g. Attrill *et al*, 1996 and Thames Estuary Benthic Research Group, 1997). Whilst ecologically the creeks may be considered as part of the main river, their distances of upstream tidal penetration from the main river are often considerable; their water circulation is different and complex and these environments provide unique habitats of a nature that are often different from that of the main river. For example, at low tide Thames Estuary creeks are mostly dry. Water flowing through their central channels from upstream the tributary is basically fresh water. At high tide their salinities are slightly lower than those of their confluence at main river because of further dilution of the incoming brackish water by freshwater from upstream the tributary but obviously many times higher than at low tides. Water that empties into the creeks originates and flows through regions of different biogeography and thus has ecological properties different from the part of the main river they empty into. This study aimed to evaluate the benthic macroinvertebrate fauna of the creek environments separately using appropriate methods and techniques in order to compare their assemblages to that of the main river and the dock basins.

It is often the case that fish and macroinvertebrate community composition studies do not consider fish diets in their methodology. Thus potentially important ecological interactions between macroinvertebrates and fish residing in the same environment or even the interactions between individuals of different fish species are ignored. An important question for the Thames Estuary fisheries is: apart from chemical and physical factors what biological factors limit the productivity of the estuary? Richardson (1993) reviewed several lines of evidence about factors of productivity in estuaries and reached the conclusion that fish production is limited by benthic production. Evidence also indicates that some habitats may contribute more than others to productivity of higher trophic levels such as fish. In a low-gradient, warm-water river, Benke *et al.* (1984) found that woody-debris habitats represented only 4% of total benthic habitat but contributed 60% to total invertebrate biomass and 16% of total invertebrate production in a study reach of the Satilla River, Georgia. Four of the eight major fish species in the Satilla obtained at least 60% of their diet from snag-inhabiting invertebrates, and significant portions of the diets of piscivorous species relied on prey that used snag-inhabiting invertebrates in their diets. A disproportionate contribution of specific habitats to invertebrate production and/or drift, which is subsequently available at higher trophic levels, can have far-reaching consequences for fisheries management. However, such contributions are rarely assessed. In the current study it was postulated that the upper and middle Thames Estuary, the Royal and the East India Dock Basins and the estuarine creeks would have different fish and benthic macroinvertebrate assemblages in terms of both numerical abundance and community structures but of similar species compositions. Over biogeographic history, fish and macroinvertebrates that originally evolved in isolation within divergent rivers and tributaries, lake basins or that have been fragmented by organic pollution have subsequently gained access to the same drainage systems, and today share habitats. In the current study an attempt will be made to relate distribution patterns of fish not only to the described physicochemical environment but also to examine the availability of food at the different ecological regions and the feeding preferences of different species of fish predators in relation to the availability of invertebrate prey and other food sources.

In some situations, analysis of various habitats will require a substantial effort. For example, Baker *et al.* (1991) delineated about 13 different freshwater habitats along a reach of the lower Mississippi River. Obviously, biotic inventories in this large riverine system require tremendous effort and assessing productivity and processes in such diverse systems demands even more effort and resources. Numerous direct and indirect linkages between habitats add another layer of complexity. As pointed out by Richardson (1993), most models of river ecosystem function have addressed flow of energy and materials without incorporating feedback mechanisms that regulate population and trophic interactions. Most of these studies have failed to identify feedback loops that may be strongly regulating in river ecosystems. The task of identifying such feedback loops will be formidable. Clearly, unless outside energy subsidies are greater than in-stream food resources for fish, effective fisheries management must account for fish-invertebrate linkages and macroinvertebrate linkages with resources and habitats. One of the aspects of the current study is an investigation of the relationship between fish and macroinvertebrate fauna of the Thames Estuary.

1.3 The aims of the study

The primary aim of the current study is to contribute to the knowledge of the present status of fish and macroinvertebrate assemblages in the upper and mid Thames estuary and some of their associated creeks, tributaries and dock basins. It is based on the following objectives:

1) A macroinvertebrate survey of the upper and mid Thames estuary, 5 estuarine creeks (Chelsea, Deptford, Bow, Barking and Dartford creeks), the Royal Dock Basins, East India Dock Basin and Dartford Creek Channel system;

2) A fish survey of the upper and mid Thames Estuary, Queen Victoria Dock Basin and East India Dock Basin;

3) Accessing recent fish survey data from the Dartford Creek Channels system (River Cray).

These studies were made possible through cooperation with the Environment Agency (South Thames Fisheries Department).

The specific objectives of this study were to determine the following aspects of the ecology of the middle and upper Thames estuary and its associated creeks, docks basins.

1. to assess fish distribution and population structure in the upper and mid estuary over a period of 12 months in order to determine breeding periods and populations and community responses to seasonal changes;
2. to assess fish populations, species composition and population structure in the East India and Queen Victoria dock basins;
3. to assess fish populations, species composition and population structure in the Dartford Creek also serving as a main tributary discharging into the middle reaches of the estuary in order to assess the similarities and differences in the species assemblages between the creek and the main river (the estuary);
4. to carry out fish age distribution analysis for the upper and mid Thames Estuary;
5. to analyse and compare the population structure of the fish in each of the above habitats to determine the contribution of habitat complexity/heterogeneity to species composition and community structure;

6. to assess similarities and differences in the fish species populations, composition and community structure in the various habitats and, in particular, consider the potential role of the dock basins, creeks and tributaries as refugia for the juveniles of different fish species in winter;
7. to study benthic invertebrate diversity and relative abundance in the range of habitats stated above and additional Royal dock basins (King George V and Royal Albert dock basins) and four other estuarine creeks (Chelsea, Deptford, Bow, Barking and Dartford creeks);
8. to study gut contents of fish in the estuary to assess the importance of invertebrates as food items for different fish species and size groups for the summer and winter season.

The achievement of these objectives was attempted through extensive field sampling and laboratory analysis of fish and benthic fauna within the areas mentioned above. The data obtained was analysed using appropriate descriptive and statistical methods using Minitab and Microsoft Excel for Windows.

1.4 Structure of thesis

The investigations which form the basis of this thesis comprise three principal lines of investigations namely: invertebrate distribution, population structure and seasonality; fish distribution, population structure and population dynamics and seasonality; fish gut contents analysis and food selectivity for the most abundant fish species. The remainder of this thesis is therefore organised as follows:

Chapter 2: Sampling sites selection and site description;
Chapter 3: the distribution and abundance of benthic macroinvertebrate species in the upper and middle Thames estuary and its associated dock basins and creeks;
Chapter 4: the composition and relative abundance of fish species in the upper and middle Thames estuary and its associated tributaries and dock basins;
Chapter 5: ontogenetic, spatial and temporal analysis of the gut contents of the 12 most common fish species in the upper and middle Thames estuary;
Chapter 6: Discussion, conclusion and recommendations for further studies.

Chapters 3 – 5 are stand-alone chapters and include methods, results and discussion sections. Chapter six draws the three lines of investigation together so that overall conclusions can be drawn and recommendations for further research can be made.

Chapter 2

SAMPLING SITE SELECTION AND SITE DESCRIPTION

Following formulation of the objectives detailed in Chapter 1, sites were chosen in the upper and mid Thames Estuary, the Royal Dock Basins, East India Dock Basin, Chelsea, Deptford, Bow, Barking and Dartford Creeks for the fish and macroinvertebrates collections. Sites were chosen on the basis of three main criteria 1) representation of the environments under investigation; 2) previous research activities by the Environment Agency; 3) accessibility and practicality of sampling. Unfortunately, the highly modified nature of the Thames Estuary restricted access and safety consideration often meant that these were often the overriding factors in site selection. Individual sites are described following a detailed description of the physical features of the Thames Estuary and these associated habitats.

2.1 Physical features of the sampling Environments

Physical features of the Thames Estuary

The term Tidal Thames or Thames Estuary refers to the part of the river extending upstream to Teddington Weir, and downstream to the seaward end of the estuary (Environment Agency, 1997). From the Teddington Weir to the edge of the estuary east of Southend-on-Sea, this section of the River Thames measures approximately 111 – 130 km depending on the definition of the seaward limit in length. Traditionally all positions along the length of the estuary have been measured with respect to their distance from London Bridge and this convention has been followed in this study.

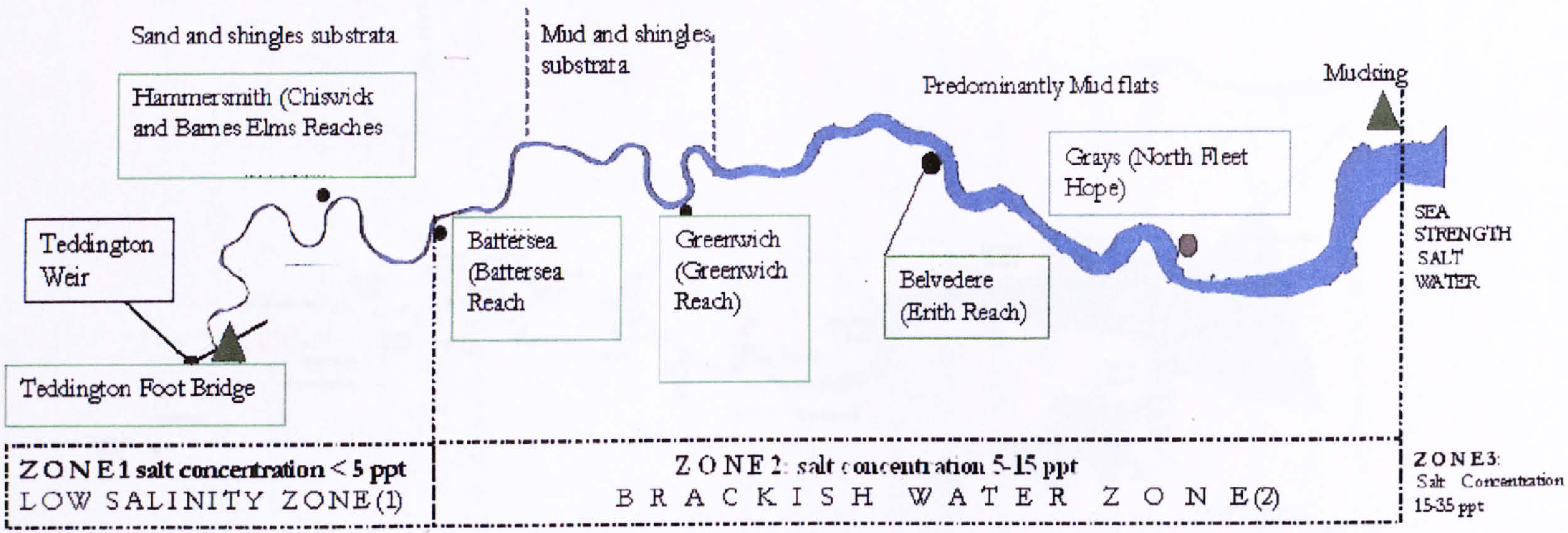
The physical limits of the estuary thus extend in the landward direction to Teddington Weir, 30.5 km above London Bridge, which represents the highest point of tidal influence although the lock at Richmond 25 km above London Bridge retains the water at a half-tide level during the ebb, a navigational necessity for boats moored between the two locks.

The seaward limit of the estuary remains more difficult to define and has been the area of inconsistent boundaries. The salinity levels approach the marine conditions, above 28 ppt approaching 35 ppt beyond Southend, 70 km seaward of London Bridge. Several limits have been drawn on maps. Since 1894, the Thames Conservancy established the seaward limit of the Thames Estuary 80.5 km seaward of London Bridge. The seaward limit in some studies is taken to be the line joining Southend and the Isle of Grain; but the Port of London Authority extends its seaward limit a further seven miles to Shoeburyness (74 km below London Bridge). Andrews *et al* (1992) used a seaward limit an imaginary line joining Haven point (96 km downstream of London Bridge) in Essex and Waden Point on the Isle of Sheppey in Kent (Figure 2.2).

Various names have been used in order to define the sections of the estuary. According to the Environment agency (1997) there are three denominated reaches in the estuary: Zone 1) Upper estuary - from Teddington to Battersea, with 25 km of length, corresponding from 30.5 km above London Bridge to 5.5 km above London Bridge; Zone 2) Middle estuary - from Battersea to Mucking, with 60 km of length, corresponding to 6 km above London to 55 km below London Bridge; Zone 3) Lower estuary - from Mucking to Seaward limit, corresponding to approximately 35 km of length. This study only focuses on Zones 1 and 2 (the upper and middle estuary respectively) (see Figure 2.1.)

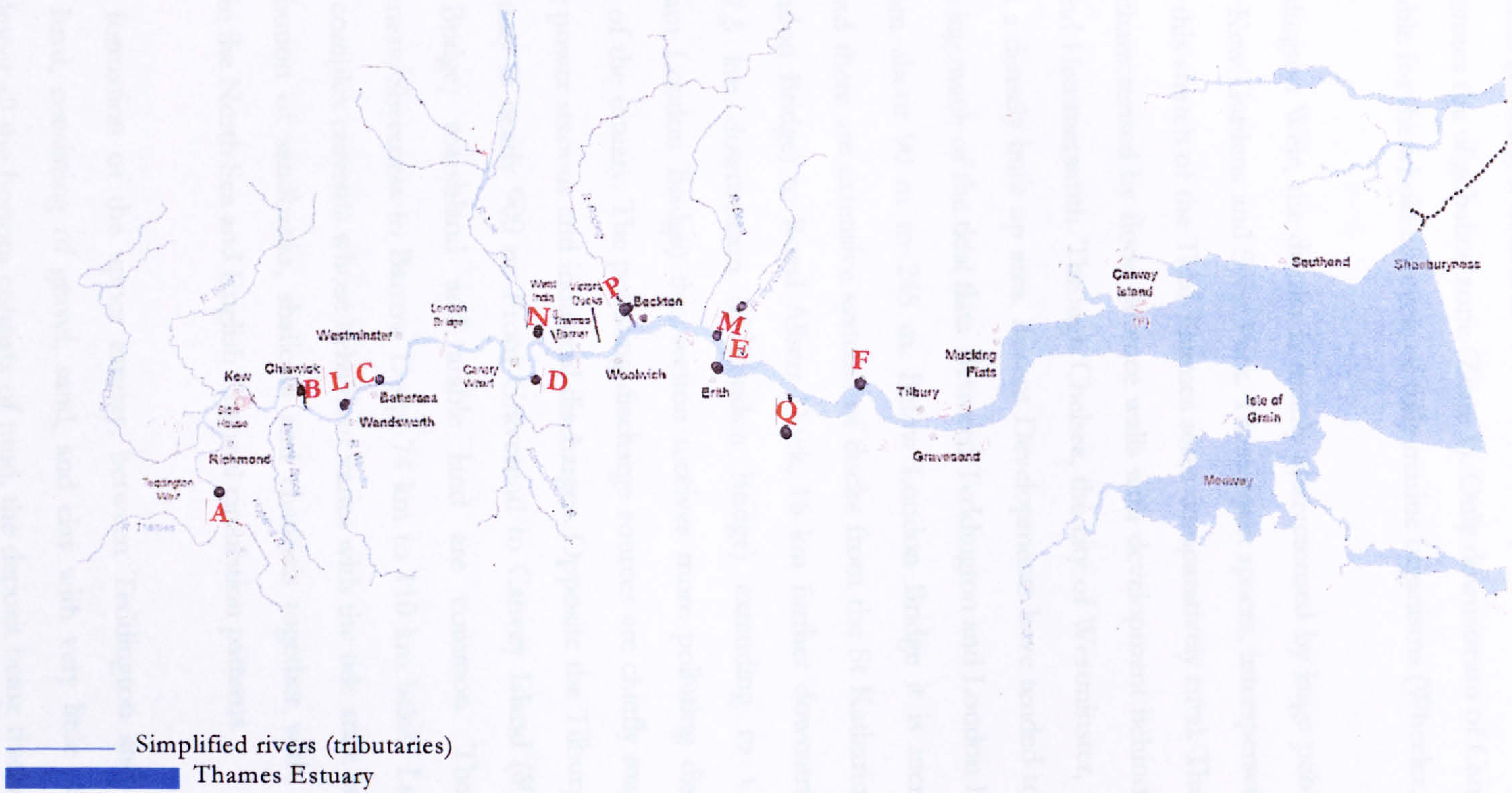
The upper estuary, (Zone 1), consists of predominantly fresh water or water of very low salinity, <5 ppt. The substratum in Zone 1 is predominantly made of shingle and mixture of shingle and sand. The middle estuary (Zone 2) consists of brackish water (5-15 ppt). The substrate here is predominantly fine sediments or deposited particulates, although shingle and sand deposits frequently interrupt the continuum. The Lower Estuary Zone 3 is 15-28 ppt salinity. Zone 3 is characterized by deep water and high currents although the wave energy of the North Sea is well reduced (Figure 2.1). The water here is reasonably transparent because of very low freshwater input. At the entrance of the tidal water (Southend) the sediments are still sandy and completely oxidized, but beyond the influence of the strong currents, i.e. areas starting from Gravesend, reducing conditions occur a few millimetres below the sediment surface.

Figure 2.1 Map of the Thames Estuary showing the salinity zones and major substrate types



Scale 1:100,000 or 10 km to 1 cm (based upon 1/100000 ordnance Survey Map), Jones (1993)

Figure 2.2 Map of the Thames Estuary Showing main features and sampling sites



A Teddington
B Hammersmith
C Battersea
D Greenwich
E Belvedere
F Grays
L Chelsea Creek
M Deptford Creek
N Bow Creek
P Barking Creek
Q Dartford Creek

Scale 1:100,000 or 10 km to 1 cm (based upon 1/100000 ordnance Survey Map), Jones (1993)

This area of reduced sediments extends from Gravesend to the Docklands just above the Thames Barrier. From the sea towards the upper reaches, there are distinct changes in depth, physical energy levels (currents and turbulence), water clarity, salinity, chemical concentrations, oxidizing and reducing conditions. The salinity reduces steadily inland from the sea. The high salinity area of the river (15-28 ppt) is known as polyhaline (Zone 3), middle salinities (15-28 g/l) constitute the mesohaline (zone 2), and the very low salinity (< 5 ppt) constitutes the oligohaline zone (Zone 1). Only downstream of Canvey Island is the salinity suitable for the whole life cycle of fully marine organisms (Wheeler, 1979).

Below Teddington Weir, the district is mainly characterised by large public parks such as Richmond, Kew Gardens and Syon Park. These open spaces, interspersed with residential areas make this stretch of the Tidal Thames seem comparatively rural. The more urbanised riverbank, characterised by flood defence walls with development behind, begins between Chiswick and Hammersmith. Through Chelsea, the city of Westminster, to Tower Bridge, the bank is a densely built up area. Recent Developments have tended to build out in the river removing much of the tidal flats. Between Teddington and London Bridge the estuary widens from about 90 m to 245 m. Below London Bridge it is increasingly used by shipping and there are extensive systems of docks from the St Katharine Docks (1.5 km below London Bridge) to Royal Albert Dock, 16 km further downstream. Beyond this region (17.5 km downstream of London Bridge) extending to Gravesend (42km Downstream London Bridge) this section receives more polluting discharges than any other part of the estuary. The polluting discharge sources are chiefly major sewage works, generating power stations and industrial discharges. Opposite the Tilbury Docks the width of the estuary is nearly 900 m. From Gravesend to Canvey Island (60 km downstream London Bridge) marshland and arable land are common. The 'Outer' estuary (Shoeburyness/Sheerness to Barrow Deep, 74 km to 110 km below London Bridge) is a region of complex currents whose behaviour varies with the tide state and is influenced by the distribution of sandbanks, shallows and channels together with seasonal and tidal variation in the North Sea and English Channel circulation patterns.

The bed formation of the upper estuary, between Teddington and London Bridge is generally hard, consisting of gravel, sand, and clay with very little mud. In the middle estuary, almost all the bottom consists of mud, the deposit being thickest between 16 and 24 km below London Bridge which is by far the largest deposit of mud in the estuary. From the seaward end of Erith (29 km below London Bridge) to Gravesend (44 km below

London Bridge the bed is usually hard, consisting of stones, flints and clay with some patches of mud on the North side of Long Reach. From Gravesend to Canvey Island there are large expanses of muddy sand exposed at low tide.

The average tidal amplitude between high and low water range from 4.2 m at Southend to 4.6 m at Tilbury, rising to 5.0 m at Richmond Lock; there is a maximum range of 5.8 m at London Bridge (HMSO, 1964). The oscillation of the tide (tidal incursion) means that a particular point on the water surface will move backward and forward over a range of approximately 10 to 15 km in 12.5 hours depending on the geographical position of the tideway (HMSO, 1964). This implies that any particular point will experience slack water twice in the tidal cycle i.e. at low and high water. However these slack tides last for very short time (30-45 min). It is this corridor of time that is exploited in seine netting as this is a requirement for the optimum performance of the net.

2.2 Physical features of the Royal and East India Dock Basins

The Royal docks are artificially enclosed water basins into which vessels were brought for loading and unloading goods or for inspection and repair. The 250 acres of Royal Docks are unique in their scale and location (Figure 2.14). Reputed to be the largest area of impounded water in England, they comprise the main Royal Victoria, Royal Albert and King George V docks, the smaller Pontoon Dock and Albert Basin, and Gallion locks, these giving boats and ships direct access to the River Thames. Their average depth is 60 ft. They are not tidal so their waters are clear.

When the Royals Docks were closed in 1981, a huge amount of urban development took place around them from 1981 to 2005. Initially, the population of the Docklands increased slowly, by less than 1% between 1981 and 1991: from 4,178 to 4211. Major population growth around the Royal Docklands occurred in the 1990s. From 1991 to 2000 the population rose to 5,600: a rise of about 32% within one decade and today it is steadily rising.

The water areas are used principally for recreational activities, including sailing, canoeing, windsurfing, rowing, jet skiing and water skiing. A marina operates in the Albert Basin and increasing use is being made of the Royal Docks by river pleasure boats requiring access to the ExCeL exhibition centre, and as a location for television production.

Heavily built up environments now surround the Royal Docks. However, even though water in the Royal Docks is regularly pumped from the River Thames in order to maintain levels, it is of better quality than the river water and is independently confirmed as being suitable for water contact sports. Consultants contracted by the Royal Docks Management Authority regularly undertake measurements and laboratory analysis of water, to check compliance with mandatory and guideline values set out in Bathing Water (Classification) Regulations 1991. The maintenance of the Dock areas includes the routine removal of litter, debris, and flotsam. The water on occasions suffers from reduced transparency, and has an average pH of 8.5. The temperature of the water in the upper levels closely reflects the ambient air temperature, but generally only in the periods between May to early October does the temperature exceed 15 ^{0}C. The docks are usually stratified throughout summer..

The scale of urban developments on the land surrounding the dock basins and the scale of the uses, which their water has been put, means increased and disproportionate pressure on the water basins with environmental consequences for the organisms that inhabit them. The fact that both solid and dissolved particulate organic matter is much reduced will also imply consequences for organisms that depend on detritus for food. Because of the need for the water to comply with statutory standards for contact water sports, anthropogenic organic inputs are extremely low – reinforced by by-laws. Unlike the main River Thames there is no riverine detritus input due to efficient drainages surrounding the dock basins to prevent runoff or combined sewage water from the surrounding area from entering the basins system. Inputs of freshwater from rain contribute to the basin water volumes and this is believed to influence the salinity of the water in the dock basins.

The East India Dock is not part of the Royal Docks group and is a small dock basin that now opens directly to the River Thames, although with a restricted in and out flow through the now grilled locks. It now experiences tidal and salinity fluctuations after works in which Lee valley Regional Park Authority converted it into a bird sanctuary and it became part of the Bow Creek Ecology Park. The extensive environmental program has transformed the appearance of the East India Dock Basin and its surroundings. Works to this basin have included ecological landscaping and planting of *Phragmites* reeds as well as other marsh plants. This reed bed and marsh plants are now fully intertidal. However, at low tide, unlike the main river which receives freshwater from upstream, the East India Dock Basin does not receive fresh water inflow hence its salinity at low tide will be higher than that of the main river.

2.3 Physical features of the tidal creeks

The tidal creeks are dynamic and variable ecosystems. They are influenced by both the volume and quality of freshwater from upstream and salt water intrusion from downstream. In their natural undeveloped state they possess rich, marginal habitats with important intertidal mudflats, exposed at low tide, and support large numbers and a high biomass of characteristic estuarine invertebrates on which fish and waterfowl feed, (Davidson, 1991). According to Davidson (1991) such ecosystems provide important nursery grounds for a broad range of freshwater and estuarine fish species, and the extensive reed beds are often heavily utilised by fry.

Creeks are situated at the mouths of tributaries; they discharge into the estuary of the main river and become wider and shallower as they approach the main river. Low water velocity from the tributary, combined with tidal ebb and flow, creates a depositional environment. The mixing of freshwater from the tributaries and incoming tidal brackish water causes flocculation and enhances the deposition of sediments. This combined with a low flow regime leads to the creation of mud flats and deeper channels typical of the creek environment. Most of the creeks in the lower estuary have extensive flood defence structures in places forming part of London's flood defence system. The flood defence walls which line the Chelsea, Deptford and Bow Creeks, which prevent the flooding of much of East and South London, are made up of steel, concrete, bricks and wood and are in various states of decay. Along the high tide mark, terrestrial plants and shrubs have colonised the crumbling wooden fenders. Below this growth the walls are covered with green algae *Enteromorpha*. Barking and Dartford Creeks and their catchments are still very much in their original forms. Below the mud flat is the underlying substratum of the creeks; a layer of stones and gravel. The creek walls, mud deposits and central channel can be regarded as separate habitats. Each possesses environmental conditions that favour the habitation of certain organisms.

2.4 Site selection and description

Figure 2.1 shows the section of the Thames Estuary selected for this study namely the upper, low salinity, Zone 1 and the middle, brackish water, Zone 2. The six sampling stations selected on the main river are shown namely: Teddington, Hammersmith, Battersea, Greenwich, Belvedere and Grays.

2.5 Sampling Reach and sampling site selection

The Thames Estuary is segmented into reaches (Environment Agency, 1997) e.g., the Teddington Reach, the Hammersmith Reach, the Battersea Reach, Greenwich Reach, Erith Reach etc. The sampling reach is a section of river designated as the sampling unit for describing geomorphology, water quality, and fish and macroinvertebrate assemblages. The length of the sampling reach is determined by a combination of factors, including the section's geomorphology, meander wavelength, and a minimum-maximum length criterion. The primary determinant of sampling reach length is geomorphology. Sampling sites were selected within each reach. Sampling sites were generally chosen to represent the set of physical and chemical conditions deemed important for controlling the ecology of the reach. However, within these considerations other factors namely accessibility, availability of a suitable foreshore and snag free firm substrates for seine netting were considered in selecting sampling sites.

Figure 2.2 is a more spatially resolved map showing the position of tributaries, and creeks in relation to the whole river and other sampling sites.

The three main associated water courses (and water bodies) with the upper and middle estuary are:

1. Tributaries (River Darent and Cray) which include low salinity tidal areas above the tidal barriers and brackish water creeks in the tidal zone.

2. Dock basins which were constructed to hold deep water during the ebb-tides and to be able to admit large vessels for loading and unloading of cargo as well as for repairs. The basins sampled for fish include Queen Victoria Dock Basin and East India Dock Basin. The Royal Albert and King George V were inaccessible for fish sampling. The additional docks sampled for macroinvertebrates include King George V and Royal Albert dock basins. These docks, apart from the East India Dock Basin have very restricted connection with the main river and only exchange water during boat movements, when the locks are opened.

3. The estuarine creeks which include Chelsea, Deptford, Bow, Barking and Dartford Creeks. Creeks below the tidal limit may be in continuum with the main river but

may have quieter regimes. Middle estuarine creeks have extensive flood defence structures forming part of London flood defence system. The flood defence walls which line the Chelsea, Deptford and Bow Creeks, which prevent the flooding of much of East London and South London are made up of steel, concrete, bricks and wood and are in various states of decay. Barking and Dartford Creeks are still very much in their original forms. They have been little developed except for the upper reaches. Below the walls of the creeks are mud flats whose underlying substratum is a layer of gravel and stones.

Upper Estuary

Three easily accessible sites in the Upper Thames Estuary were selected. They were:
Teddington - 30.5 km upstream London Bridge (NGR TQ164717), the uppermost site and marking the end of the tideway. The half-tidal channel is made up of 90% earth and gravel shores of reinforced wood. In spring and summer the riparian vegetation forms a fairly closed canopy, which encroaches on the river at high water in the south bank. There is riverside plant community on the south bank in spring and summer (Figure 2.4). The substrate is clean mixture of sand and gravel interspersed by stones (table 2.1 and Figure 2.3)
Hammersmith - 15 km upstream of London Bridge (NGR TQ225783) - There are no mud flats at this site and there is very little variety of habitats. The substrate is clean mixture of sand and gravel (Figures 2.5 and 2.6, Table 2.1).
Battersea - 6 km upstream London Bridge (NGR TQ268773) South bank beneath and upstream of the bridge access from Battersea Park or Bridge. The shore comprises, gravel and large stones and bricks (See Table 2.1). Like the Hammersmith, site the Battersea site lacks variety in habitat distribution. The substrate is a mixture of sand and gravel but there thin mud deposits in places.

Figure 2.3 Teddington

Figure 2.4. Summer river side herb community at Teddington site

Figure 2.5 Hammersmith site at low tide

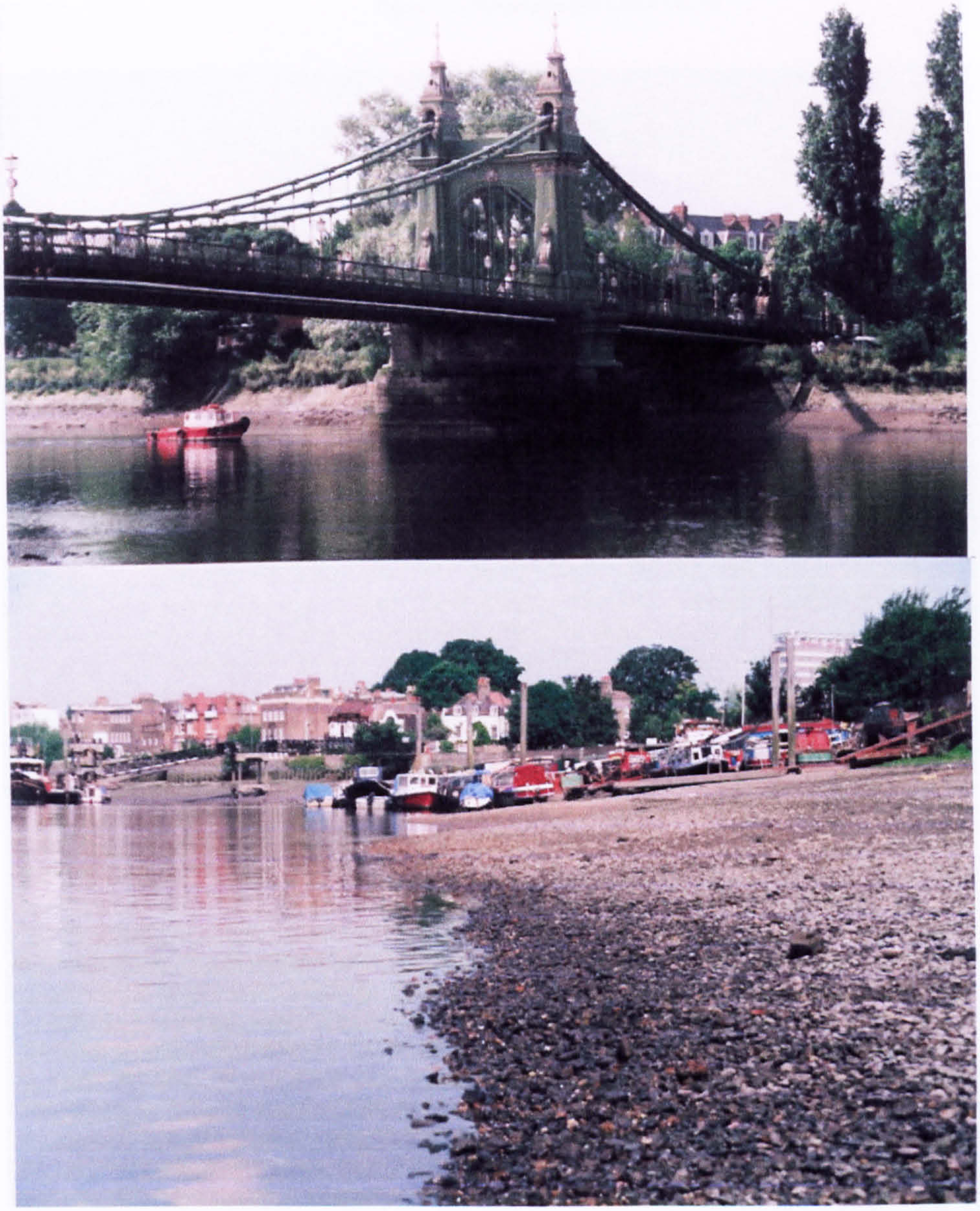


Figure 2.6 Hammersmith beach profile

2.6 The Middle Thames Estuary

This extends from Battersea to Mucking, 6 km above to 55 km below London Bridge. It is in this section that the influence of brackish water is greatest in contrast to the upper estuary where the dominant influence is freshwater. Land access to the foreshore from mid to low tide was difficult because of the flood defence walls. However, access to the foreshore was possible in places by foot (steps) at low tide. For the original collection of samples of invertebrates and fish three sites in the Mid Thames Estuary were used. They were:

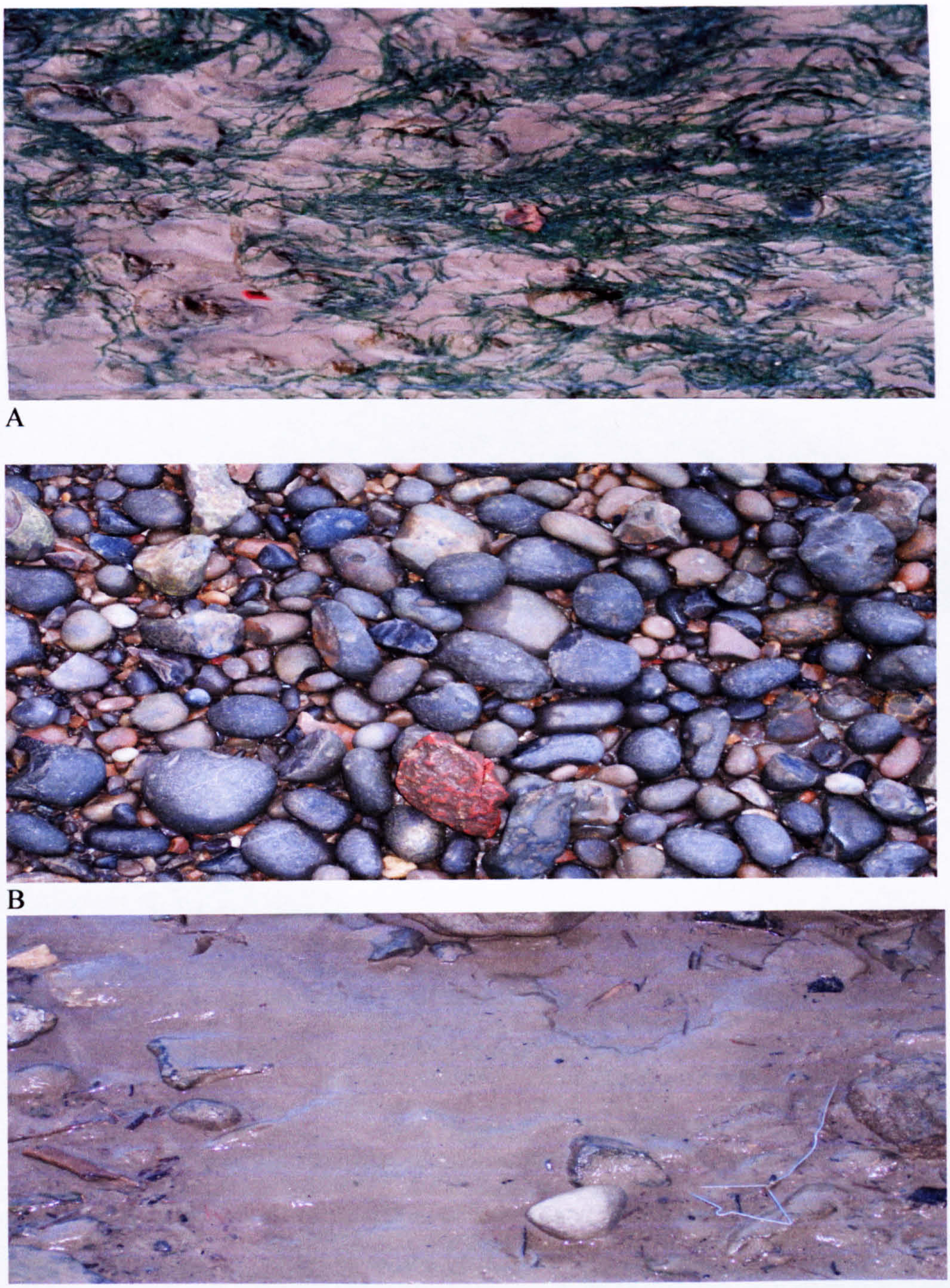
Greenwich, 7.5 km below London Bridge (NGR TQ387790) has a variety of microhabitats. The Greenwich site is characterised by the presence of a mixture of substrates, mainly thin mud flats and gravel (Figure 2.7 and 2.8, Table 2.1). The supralittoral is a high brick wall.

Belvedere is a south bank site immediately down stream of Crossness, the biggest sewage treatment works in London. The site itself receives a mixture of sewage effluent and river water. Like Greenwich, a mixture of substrates exists in Belvedere which range from rocks boulders, mud deposits and seaweed (Figure 2.9 and 2.10, Table 2.1). It is relatively underdeveloped with little in the way of the flood defences; except for boulders of granite rock laid along the entire reach to stabilise the area against erosion, as waves from shipping movement are fairly frequent and heavy here. However, despite this wave climate mud is deposited in places and there is estuarine strand line vegetation. Belvedere was originally selected as the most downstream site for fish sampling. However, the boulders posed a major difficulty when seine netting and caused frequent snagging and tearing of the net. Belvedere was therefore abandoned as a site in favour of Grays after 6 months of sampling.

Grays site is the most down stream site sampled in this study and is situated on the south bank a few miles upstream of Tilbury adjacent to a flood water gate, just outside a large grain processing plant. This site has a variety of habitats (Figure 2.11 and 2.12 and Table 2.1). At low water a zone of deep mud is exposed making it impossible for seining at low tide. At high tide the upper foreshore is occupied by clean sand. . The river is about 300 metres wide here. Fish sampling on this site started in October after the Belvedere site was abandoned because of safety problems due to sampling problems and sampling difficulties described above.

Figure 2.7. Greenwich site

Figure 2.8 Sub-habitats of Greenwich



A

B

C

A = summer mud flats colonised by blue-green filamentous algae
B = Shingle substrate found in the unsheltered part of the site
C = winter mud deposits found in the sheltered part of the site

Figure 2.9. Belvedere site foreshore profile

A = concrete reinforcement to prevent waves from undermining the wall
B = boulders interspersed with mud

Figure 2.10. Belvedere site substrate profile

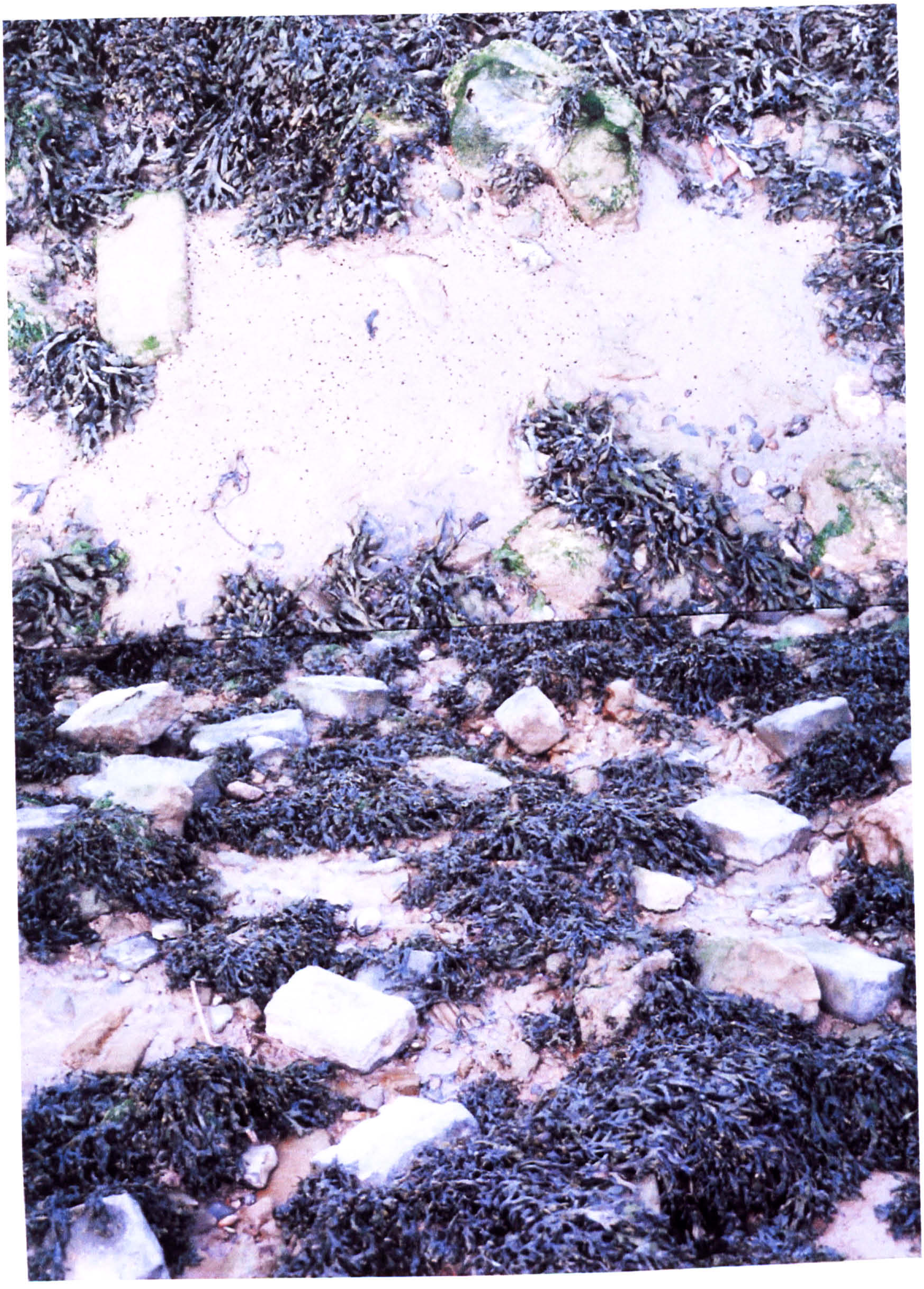


Figure 2.11 Grays site

Figure 2.12 A photograph of Grays site substrate showing the different substrates on the site. The upper part the photograph shows part of the site through which storm water flows.

Upper Thames Estuary Creek

Chelsea Creek was the only upper Thames estuary creek sampled. Salinities of upper estuarine creeks are very low. At high tide, salinities are slightly lower than the main river because they are diluted by freshwater input from upstream. Upper estuary creeks are typically less silted than their brackish water counterparts.

Chelsea Creek is located 6 km upstream of London Bridge has a flood defence wall at the mouth, muddy sand banks at low water and gravelled central channel. There is a lot of debris.

Mid Thames Estuary creeks. Tidal creeks are dynamic and variable ecosystems, influenced by both the volume and quality of freshwater from upstream and saltwater incursion from downstream. At low tide, there is always a little freshwater running through the middle of the creek, brought from the small rivers further upstream. The flowing water washes away the mud, leaving a hard stony substrate to the central channel.

Silt from the Thames brought in and deposited from the water at high tide, has created mud banks. They are covered by water at each high tide, and then exposed again as the tidewaters leave the creek. At low tide the mud is covered by single celled and filamentous blue-green algae. Below this film is a very shallow layer of brown mud overlying deeper black mud. Below the mud is the true bottom of the creek, a layer of stones and gravel.

The creek walls, central channel and mud deposits were sampled separately using suitable methods namely: wall scraping, kick-sampling and core sampling for the walls, central channels and mud deposits respectively. In the mid Thames Estuary the following creeks were samples for macroinvertebrates in the winter and summer seasons of 2002.

Deptford creek, 7.2 km below London Bridge is the mouth of the River Ravensbourne, one of the remaining tributaries of the mid Thames Estuary. The mouth of Deptford Creek is 350m to the east of the Greenwich sampling site. Because of the central freshwater channel, salinity levels in Deptford Creek range from <1 ppt at low tide to 15 ppt at high tide in the daily tidal cycle.

Bow creek, 8.1 km below London Bridge is about 1 km below the Deptford creek. Bow creek is the mouth of the River Lee, one of the major tributaries of the Thames Estuary. Because the river Lee is characterised by a series of locks, the central channel of the Bow creek is narrower and shallower due to reduced fresh water flow.

Barking creek, 20 km below London Bridge is the mouth of the River Roding. The south bank is characterised by deep mud flats. Becton Sewage Treatment Works is located upstream and adjacent to the mouth of Barking Creek. There are also chemical works, and some shipping trade, principally in timber and fish. The creek banks are mostly wide and natural with salt marshes, but reinforced in some places.

Dartford creek, 22.4 km below London Bridge is combined mouth of Darent and Cray. Dartford creek and its catchment is little developed except for its very upper reaches. For its full length the intertidal mudflats and *Phragmites* reed beds remain unspoilt. Dartford Creek has two Arms (the Crayford Arm and the Darent Arm) each of which are intertidal and of low salinity.

Figure 2.13 Deptford Creek showing the creek walls, mud banks and central channel

2.7 Thames Estuary associated dock basins

The dock basins are artificially enclosed water basins into which vessels were brought for loading and unloading goods or for inspection and repair. The 250 acres of Royal Docks are unique in their scale and location. Reputed to be the larges area of impounded water in England, they comprise:

1. King Edward V Dock Basin,
2. Royal Albert Dock Basin
3. Royal Victoria Dock Basin.

2.8 East India Dock Basin

The East India dock is not part of the Royal Docks group and is a small dock basin located in the west of the Bow Creek. East India Dock basin now opens directly to the river Thames, although with a restricted in and out flow through the now grilled/meshed locks. It is now fully tidal after works in which Lee Valley Regional Park Authority converted it into a bird sanctuary and it became part of the Bow Creek Ecological Park. Works in this basin have included ecological landscaping and planting of *Phragmites* reeds as well as other marsh plants in the eastern edge of the basin. The reed bed and the marsh plants are now fully intertidal. The substrate is estuarine mud and silt in places. The riparian vegetation is *Phragmites* reed bed and estuarine marsh vegetation. The centre of the basin is filled with gravel which forms an island at low tide. The north, south and west part of the basin is still bordered by concrete walls with no riparian vegetation.

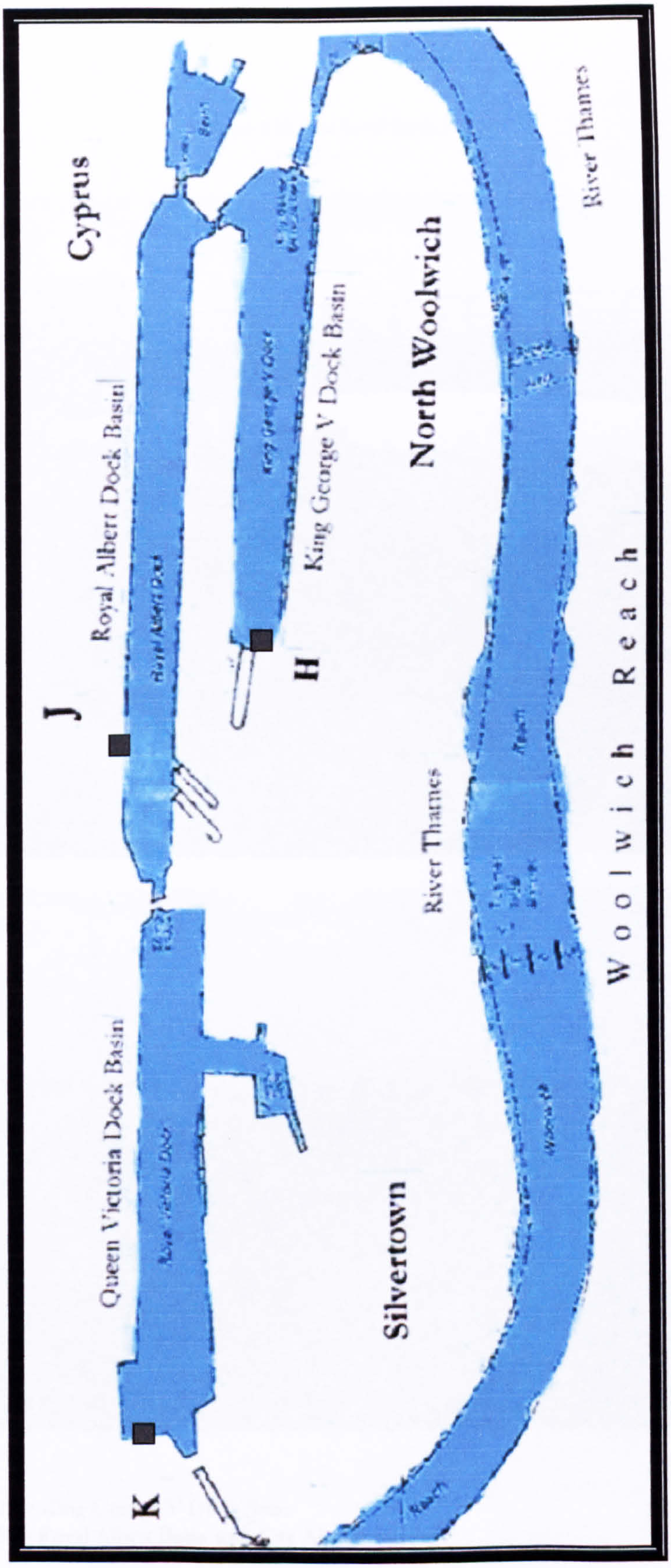


Figure 2.14.An illustrated map of the Royal Dock Basins and the Woolwich Reach of the River Thames

H = King George V Dock Basin Macroinvertebrate sampling site
J = Royal Dock Basin Macroinvertebrate sampling site and
K= Queen Elizabeth Basin Macroinvertebrate and Fish sampling Site

Figure 2.14 An illustrated map of the Royal Dock Basins and the Woolwich Reach of the River Thames

Figure 2.15 The Royal Dock Basins

A

B

A = King George V Dock Basin
B = Royal Albert Basin with City Airport runway

Figure 2.16 Queen Victoria Dock Basin

A

B

A = East side of Queen Victoria Dock Basin showing recent Development; B = West bank showing the artificial beach

Figure 2.17 East India Dock Basin showing the environmental works/enhancements

A

B

A = *Phragmites* reed bed and B = shingle island (the basin as a bird sanctuary)

Table 2.1 Habitats of the sites studied and their levels of complexity

Site	Substrate type	classification	Heterogeneity
Teddington	bacteria ooze, sandy shore, gravel beach, river side herb community, wood clear water Salinity range <1 ppt	high complexity	High
Hammersmith	Sandy shore, gravel shore, concrete walls, clear water Salinity range 1-5 ppt	medium complexity	Low
Battersea	Sandy shore, gravel shore, concrete walls, clear water Salinity range 1-5 ppt	medium complexity	Low
Greenwich	Estuarine mud, gravel shore, concrete walls, Turbid water, salinity range 5-15 ppt	medium complexity	Medium
Belvedere	Estuarine mud, boulder shore, estuarine strand line, concrete walls, salt marsh, turbid water , salinity range 5-15 ppt	high complexity	high
Grays	Estuarine mud, boulder shore, estuarine strand line, concrete walls, salt marsh, turbid water, sandy beach, salinity range 15-28 ppt	high complexity	high
Chelsea Creek	Sandy banks, bacterial ooze, gravel central channel, water clear salinity range 1-5 ppt	medium complexity	Low

Table 2.1 continued

Site	Substrate type	classification	Heterogeneity
Dartford Creek	Phragmites reed beds, mud flat banks, sandy central channel (fresh water at low tide), salt marsh, turbid water, 1-15 ppt	medium complexity	Medium
Bow Creek	deep mud flat banks, mud, sand central bank (fresh water at low tide), turbid water, salinity range 1-15 ppt	low complexity	Low
Barking Creek	Deep mud flat banks, mud, sand central bank (fresh water at low tide), turbid water, reed beds, salinity range 1-15 ppt	medium complexity	Low
Dartford Creek	*Phragmites* reed beds, mud flats banks, sandy central channel (fresh water at low tide), salt marsh, turbid water, 1-15 ppt	medium complexity	Medium
East India Dock basin	Concrete walls, estuarine mud flats, *Phragmites* reed bed, estuarine plant community, wood, riparian vegetation Salinity range 5-15 ppt, algae, *Victorella* and *Sabelaria* crusts	high complexity	High
King George V Dock basin	Concrete walls Salinity 11 ppt, algae, *Victorella* and *Sabelaria* crustations	low complexity	Low
Royal Albert Dock Basin	Concrete walls, algae, *Victorella* and *Sabelaria* crustations; Salinity 11.8 ppt	low complexity	Low
Queen Victoria Dock basin	Gravel beach (artificial), concrete walls, algae, *Victorella* and *Sabelaria* crustations Salinity 11.3 ppt	low complexity	Low

Table 2.1 and Figure 2.1 together suggest that salinity gradients and the existence of mud flats in the estuary are positively correlated. The mid estuarine sites are dominated by soft mud. The effect of the marine salts in causing fine particles to clump together is the determinant of the nature of the surfaces of estuaries. During heavy winter rains, the rain washes away the surface salts (Barnes, 1994); and the particles disaggregate and the turbidity in creeks and other mid estuarine sites increase.

Chapter 3

THE DISTRIBUTION AND ABUNDANCE OF BENTHIC MACROINVERTEBRATE SPECIES IN THE UPPER AND MIDDLE THAMES ESTUARY AND ITS ASSOCIATED DOCK BASINS AND CREEKS

3 Abstract

The diversity of benthic macroinvertebrates in the Upper (Zone 1) and Middle Thames Estuary (Zone 2) and its associated tributaries, creeks and dock basins was studied using the commonly used hand picking, kick-sampling, core-sampling and wall scraping (barking) methods to examine diversity similarity and differences in macroinvertebrates assemblages between them. Results suggested that the upper estuary sites produced the largest number of species/families and middle estuary and creek sites produced the largest number of individuals but the lowest species diversity. The Royal dock basins had specialised benthic invertebrate groups, whilst the East India Dock basin had benthic macroinvertebrates composition similar to that of the main river. The mudflat of the mid estuary creeks display very high abundances and dominances by oligochaete and polychaete worms; and their central channels by freshwater species (mainly of upstream of the tributary origin). The study also indicated that habitats with similar physical and other environmental conditions yielded similar macroinvertebrate assemblages.

3.1 Introduction

The ecological zones and sites described previously in Chapter two were sampled using the methods described in the following sections. The macroinvertebrate dataset obtained from the sampling program were analysed using statistical methods described below in order to be able to investigate the primary ecological features of the macroinvertebrate assemblages in these ecological zones, in particular to be able to find the differences and the similarities between them. The primary objective of the macroinvertebrate study was to find out how the benthic macroinvertebrate population of Zones 1 and 2 of Thames Estuary, the Royal and East India Dock Basins and 5 estuarine Creeks are related to each other. Surely another main objective was to look at food availability and fish species distribution and feeding preferences. Total densities, taxonomic composition, species richness, percentage composition of the dominant species, the Shannon-Weaver index of species diversity and similarity measures (Simple Correspondence Analysis) were the quantitative and qualitative approaches used to analyse the winter and summer benthic macroinvertebrate datasets.

3.2 Sampling methods

The macroinvertebrate community was investigated in two zones of the estuary: 1) Upper Estuary sites between Teddington and Battersea; 2) Mid Estuary sites between Battersea and Grays; 3) One site in one creek in the upper estuary (Chelsea Creek); 4) Four sites in four creeks in the middle estuary (Bow, Deptford, Barking and Dartford Creeks); 5) Three sites in three Royal Dock basins (King George V, Royal Albert and Royal Victoria dock basins) and 6) One site in the East India dock Basin. The summer macroinvertebrate data for the upper and mid Thames Estuary, Deptford and Dartford Creeks were provided by the Environment Agency. This study adopted the same methods used by the Environment Agency to obtain the macroinvertebrate datasets obtained from them.

Over the past several decades, many different types of sampling devices have been invented for the systematic collection of benthofauna, for example, the Surber sampler, (Surber 1937), the Hess sampler, (Hess 1941), the Artificial Substrate Sampler, Thorne and William (1997) etc. The Hess and Surber samplers are suitable for use in streams. Four sampling methods were used in the current study.

3.2.1 Kick sampling

Kick sampling was used in Teddington, Hammersmith, Battersea, Greenwich, and the central channels of the creeks. The substrates in these sites are made up of cobbles, stones, boulders, shingle etc. In this method, a kicking action was done in front of a square-frame net sampler consisting of 500μm mesh attached to a 1.5m handle. The substratum was agitated to dislodge any macroinvertebrates that may be hiding beneath them. The kick net was opened in the water along the trail of disturbed substratum orientated perpendicular to the water flow for three minutes. If the tide was completely slack, a backward movement was made and the net was orientated along the path of the feet to ensure that the net trapped dislodged organisms along the path of movement. Stones entering the kick net were removed from within the materials picked up by the net. Organisms attaching to the stones were carefully brushed or washed with a pastry brush specially adapted for this purpose.

Standardisation of the sampling effort involved the use of a pre-defined area of 1 m^2 3 minutes of kicking for each sample. Sampling by area reduced the likelihood of variation in data due to differences in the enthusiasm of field staff and was consistent with Dine and Murray-Bligh (2000). Three replicate samples were taken in each site. If macroinvertebrate samples seemed low when collecting samples, collection of additional samples of standard sampling effort was carried out rather than simply increasing sample sizes. Replicate samples were processed separately and were not combined. After a sample was collected the organisms were rinsed into the end of the net. At shore side the benthic organisms and any other materials that may be in the sample were washed into a plastic tray.

Organisms clinging to the net were removed by hand and added to the same sample bucket. The sample was then transferred to a screw cap plastic jar and preserved in 4% formalin solution for subsequent identification and enumeration in the laboratory.

3.2.2 Wall scraping

This method involved the scraping of algal encrustations from the walls of dock basins or sea defence walls to dislodge the invertebrates residing in them. Wall scraping was the only feasible method in the deep Royals Docks except in the Queen Victoria basin where kick sampling was also carried out in the artificial beach at the south end. The use of artificial substrate samplers was tested in the Royal Albert and King George V basins but these yielded few if any organisms and their use was abandoned. To achieve consistency in sample collection, ten replicate samples each of 100cm^2 were taken from each site. The scraped substrate was stirred in a white tray containing water, sieved through a 0.5mm sieve and then returned to a white tray from which the macroinvertebrates were then picked out carefully. To ensure that organisms that hide in crevices were removed, a small pointed metal tool was used to remove substrates in crevices. Scraping was also done carefully in order to minimise damage to organisms.

3.2.3 Core sampling

A cylindrical 10cm diameter PVC core sampler was used to collect organisms that resided in the mudflats of Greenwich, Belvedere, Grays, and the Mid Estuary creeks (Deptford, Bow, Barking and Dartford). Samples of macroinvertebrates were collected in the winter and summer of 2002, from three sub-sites at each site. At each sub-site 10 samples were randomly collected, from a 15m length of the channel, with the 10 cm core sampler. A preliminary study using the Bros and Cowell (1987) technique for optimising sample size showed that 10 replicates provided a resolving power that did not change appreciably with additional samples. With this procedure, 210 samples each season and 420 for the year were taken. Sampling was always initiated at the downstream end and then progressed upstream. Care was taken to avoid disturbance of the stream bed whenever possible. Each sample consisted of approximately 10cm depth of substratum, with the associated twigs, macrophytes and detritus, and 10-20cm of water above. To ensure consistency in sampling, the same core sampler was used through out the survey. The 10cm mark was highlighted on the PVC sampler to ensure that the same depth of mud substrate was always sampled. Cores taken were immersed in a bucket filled with water and the mud was stirred to a homogeneous mixture. The muddy water of the bucket was then poured through a 0.5mm sieve, and the sample filled with additional water if required. Samples were then poured in 4% formalin in screw top plastic bottles for subsequent sorting, identification and counting in the laboratory.

3.2.4 Hand Picking

Hand picking involved no specialised equipment. A pair of laboratory specimen gloves (optional), a pastry brush, a pair of tweezers and a white plastic tray with water in it was all the equipment needed. Hand picking involved looking for the benthic organisms in the substrates. This method was employed in combination with kick and core sampling in all the sites to explore the bottom of large rocks, stones boulders and industrial materials such as building wastes. To ensure consistency in hand picking, a pre-defined area of $0.25m^2$ was demarcated for 10 minutes of hand picking. Four replicate samples were taken from each site. The boulders or stones were lifted carefully and the organisms on the surface of the bottom side of the rock were collected by dislodging them with a brush into the tray or hand picked and placed in the same sample tray. The areas where the rocks were removed were also explored and any organisms found on them were collected and placed in the tray. Some organisms are not nektonic and do not move freely within the water. They hide or adhere underneath rocks, stones, woody debris etc. Hand picking was the most appropriate method for sampling organisms that are not readily dislodged by kick sampling. Some macroinvertebrates have very narrow microhabitat requirements and/or may achieve very high densities when environmental conditions are favourable. For example a close look was required in coarse substrates at Teddington and Hammersmith for worms which generally had a well defined territory and preference for decaying vegetation and organic matter. They often occur in very high abundance in such specialised microhabitats that have a supply of organic matter. Samples collected were separated by habitat. A kick net was used to scoop up large colonies.

3.2.5 Sample processing

A full count with sub-sampling option was used although this was time consuming. A full count with sub-sampling provided a direct measure of abundance (and percentage composition) and was necessary because direct statistical comparisons of abundance or metrics requiring numerical data were employed. Quality control was achieved by checking the sorted detritus to ensure that target organisms had been removed. A fixed-fraction sub-sampling option was presented for the fixed fraction sampling of very abundant taxa (the Oligochaetes and Polychaete worms) to save time. The following sub-sampling and counting protocol was used.

3.2.6 Procedure: sorting, identification and counting of macroinvertebrates

The sample was fractionated using sieves and each fraction placed in a separate white tray. Starting with the largest size fraction, work was carried out systematically across each tray removing all of the organisms in the sample. Organisms >0.5mm total length could be identified without additional magnification. The organisms of each taxon encountered were placed into separate Petri dish to confirm identifications by microscopic examination (if necessary). All organisms were identified using macroinvertebrate keys (Brinkhurst, 1982; Barnes, 1994; Budd, 2003). The level of identification required was species level where possible and family level where a species level identification was not possible. A label was placed in the vial or bottle noting the site code/name, date, sample type, and collector's name. On completion of sample processing, there were labelled vials or bottles containing sorted organisms.

3.2.7 Sub-sampling option

Only very abundant taxa (Oligochaete and Polychaete worms) were sub-sampled. Full counts were made for all other taxa). Sub-sampling of very abundant taxa (> 500 individuals) saved considerable time. The number of individuals of each very abundant taxon from a fixed fraction (between 25% and 50% of the sample grids for each sorting tray were counted and the contents scaled up pro rata. The count estimate was recorded on the bench data sheet and noting that the value was a sub-sampling estimate. Full results for the macroinvertebrate surveys are presented in Tables 3.1 and 3.2 for the main river, Tables 3.5 and 3.6 for the dock basins and Tables 3.7 and 3.8 for the estuarine creeks.

3.3 Data Analysis methods

3.3.1 Statistical procedures

Population densities, diversity, richness and similarity measures were used to analyse the macroinvertebrate dataset obtained from the sorting, identification and counting of the invertebrate dataset.

3.3.2 Species lists

The identification and counts of invertebrates were used to develop species lists and relative abundance at each sampling station and sampling occasion. The data collected was used to examine seasonal and habitat variation in the availability of invertebrates as potential fish food.

3.3.3 Similarity Analysis

Correspondence analysis was primarily a technique for representing the rows and columns (in this study the sites and species respectively) of a two way contingency table in a joint plot known a factorial map. Correspondence analysis was an appropriate method to use for the analysis of categorical data; it avoided the unease of using traditional multivariate techniques such as factor analysis on such data. It produced visual representations of the relationship between sites and species. Correspondence analysis was used to represent the interrelationships of categories of sites (variables) and invertebrates species (observations) on a two dimensional map.

Invertebrate counts were standardised using the following mathematical expression to transform the data and to remove zero values: $\mathrm{Log}_{10}\,(100y + 10)$. Where y was the number of macrofaunal organisms of a species counted for the site. Simple Correspondence Analysis was one of the methods used to analyse the data to detect similarities between sites and macro-invertebrate occurrence and relative abundance. In this method the x^2 distance coefficient, (Lebart *et al* 1984 and Timm, 2002) was used to calculate the association matrices for the columns (variables). The eigenvalues and eigenvectors for the columns were then computed, followed by the computation of the row (sites) vectors by projections. This type of analysis projects onto a factorial map the different macroinvertebrates assemblages according to the habitats they share in common. Their geographical proximity on the factorial map thus illustrates their faunal similarity. Similarly the species responsible for the similarity or difference between sampling zones are also identified by the analysis. Additionally, in order to analyse spatial and temporal variation of species richness and evenness, the values of the Shannon-Weaver heterogeneity indices were calculated for winter and summer for each sampling region/s

3.3.4 Shannon-Weaver Index

Abundance or diversity indices are most suitable for use with benthic organisms because they are less mobile and reflect the situation *in situ* rather than elsewhere. There are many indices used to describe the diversity of benthic macro-organism, some of which are described in detail by Thorne and Williams (1997). A typical sample of these indexes is the Shannon-Weaver index (Shannon and Weaver, 1949) which is defined as:

$$H = -\sum p_i \ln pi$$

The term p_i is the proportion of a particular species in a sample which is multiplied by the natural logarithm of itself. H is derived by summing the product for all species in the sample. The minus sign is to make the final value of H positive. The index was computed for invertebrate communities of every site/locality. This index was used to aid comparisons of the community structure of sites along the upper and mid Thames Estuary and the water systems associated with it.

3.4 Results

The results of the summer and winter macroinvertebrate sampling in the main river are summarised in Tables 3.1 and 3.2. Fifty-nine invertebrate species were identified from the main river summer samples and 54 from the winter samples with 17 of these coming from a single group the Oligochaeta. Oligochaeta were the most abundant class of macrobenthic organisms in the samples. Organisms belonging to the families Chrysomelidae, Tipulidae, Psychodidae, Chironomidae, Ascaridae, Nematoda and Enchytraeidae were identified to their family levels because of lack of appropriate keys detailing the physical features of species within these families. In summer oligochaete species contributed 97.57% by numbers (not by biomass). The family Enchytraeidae contributed 63.8% numerically. In winter samples, oligochaete species contributed 98.23% numerically of which oligochaete organisms belonging to the Enchytraeidae family were the most abundant (43.4%) by numbers.

Table3. 1 Summary of summer macroinvertebrate densities (no. m^{-2}) for sites along the main river (organisms arranged in alphabetical order)

Species (summer)	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays	Total	Mean	% prop
Acari sp.	0	50	0	0	0	0	50	8.3	0.004
Amphicaeta sannio	0	0	0	37700	17640	2700	58040	9673.3	4.4
Anotylus sculpturatus	12	0	0	0	0	0	12	2.0	0.001
Anurida maritima	0	0	48	0	500	0	548	91.3	0.04
Asellus aquaticus	23	7	0	0	0	0	30	5.0	0.002
Assiminaea grayana	0	6	0	0	0	0	6	1.0	0.0005
Balanus amphitrite	0	0	13	66	34	0	113	18.8	0.01
Balanus improvisus	0	0	0	210	64	58	332	55.3	0.02
Branchiura sowerbyi	1200	2000	0	0	0	0	3200	533.3	0.24
Carcinus maenas	0	0	0	0	0	25	25	4.2	0.002
Chironomidae sp.	50	0	0	0	0	0	50	8.3	0.004
Chrysomelidae sp.	17	0	0	0	0	0	17	2.8	0.001
Corophium anenarium	0	0	0	0	8000	5100	13100	2183.3	0.99
Corophium bonnellii	0	0	0	1256	0	0	1256	209.3	0.09
Corophium lacusta	0	0	63	55	9	9	136	22.7	0.01
Corophium volutator	0	0	0	224	3070	6800	10094	1682.3	0.76
Crangon crangon	0	0	0	105	132	132	369	61.5	0.03
Deroceras reticulatum	50	0	0	0	0	0	50	8.3	0.004
Dreissena polymorpha	2	0	0	0	0	0	2	0.3	0.000
Eiseniella tetraedra	0	440	7058	0	0	0	7498	1249.7	0.6
Enchytraedae	3000	8880	70842	440000	258000	66666	847388	141231.3	63.8
Eriocheir sinensis	0	0	3	2	4	3	12	2.0	0.001
Erpobdella octoculata	13	0	0	0	0	0	13	2.2	0.001
Erpobdella testacea	19	0	0	0	0	0	19	3.2	0.001
Gammarus duebeni	25	2	0	0	0	0	27	4.5	0.002
Gammarus salinus	0	0	0	80	32	32	144	24.0	0.01
Gammarus zaddachi	172	168	149	132	80	20	721	120.2	0.05
Glossiphonia complanata	3	4	0	0	0	0	7	1.2	0.001
Glossiphonia heteroclita	6	6	0	0	0	0	12	2.0	0.001
Gyrinus marinus	5	0	0	0	6	0	11	1.8	0.001
Haliplus immaculatus	7	0	0	0	0	0	7	1.2	0.001
Helobdella stagnalis	7	40	0	0	0	0	47	7.8	0.004
Heterochaeta costata	0	0	0	26100	17640	6580	50320	8386.7	3.8
Hydrobia jenkinsi	0	10	0	72	230	220	532	88.7	0.04
Hydrobia neglecta	0	0	0	60	340	232	632	105.3	0.05
Hydrobia ulvae	37	0	18	27	710	960	1752	292.0	0.1
Jaera albifrons	0	0	0	0	26	7	33	5.5	0.002
Jaera nordmanni	0	0	0	0	13	15	28	4.7	0.002
Limnodrilus cervix	0	704	1960	0	0	0	2664	444.0	0.20
Limnodrilus claparedianus	4798	880	4704	0	0	0	10382	1730.3	0.8
Limnodrilus hoffmeisteri	8998	2816	4706	52200	5880	11280	85880	14313.3	6.5
Limnodrilus variegatus	0	132	784	0	0	0	916	152.7	0.07
Lumbriculus variegatus	0	264	0	0	35280	14100	49644	8274.0	3.7
Lymnaea peregra	3	0	0	34	69	58	164	27.3	0.01
Lymnaea truncatula	8	0	0	68	48	16	140	23.3	0.01
Monopylepthorus rubroniveus	0	0	0	0	17640	7520	25160	4193.3	1.9
Nematoda sp.	0	0	0	0	236	0	236	39.3	0.02
Nephtys hombergi	0	0	0	0	102	72	174	29.0	0.01
Nereis diversicolor	0	0	0	19	420	220	659	109.8	0.05
Oniscus asellus	0	0	4	0	0	0	4	0.7	0.0003
Palaemonetes varians	0	0	0	76	120	35	231	38.5	0.02
Paranais littoralis	0	880	4314	0	0	0	5194	865.7	0.4
Perinereis cultrifera	0	0	129	124	68	0	321	53.5	0.02
Potamothrix hammoniensis	0	0	0	0	26460	5640	32100	5350.0	2.4
Psammoryctides barbatus	0	528	3138	40600	0	0	44266	7377.7	3.3
Psychodidae sp.	19	0	0	0	0	0	19	3.2	0.001
Sphaeroma hookeri	0	0	7	0	61	20	88	14.7	0.01
Thalassodrilus prostatus	0	0	0	31900	0	0	31900	5316.7	2.4
Theodoxus fluviatilis	12	0	0	0	0	0	12	2.0	0.001
Tipulidae sp	30	0	0	0	0	0	30	5.0	0.002
Tubifex pseudogaster	0	0	0	0	14700	7520	22220	3703.3	1.7
Tubifex tubifex	11996	1320	6274	0	0	0	19590	3265.0	1.5
Total density	30512	19137	104214	631110	407614	136040	1328627	221437.8	100.00

Table 3.2 Summary of winter macroinvertebrate densities (no. m^{-2}) for sites along the main estuary (organisms arranged in alphabetical order)

Species (Winter)	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays	Total	Mean	% prop
Amphicaeta sannio	0	0	0	24700	30120	1850	56670	9445	6.8
Asellus aquaticus	8	4	3	0	0	0	15	2.5	0.002
Assiminaea grayana	0	13	1	0	0	0	14	2.3	0.002
Aurelia aurita	0	0	0	0	0	10	10	1.7	0.001
Balanus amphitrite	0	0	0	6	32	23	61	10	0.01
Balanus improvisus	0	0	0	41	62	32	135	23	0.02
Branchiura sowerbyi	1020	1740	0	0	0	0	2760	460	0.3
Carcinus maenas	0	0	0	0	0	42	42	7.0	0.01
Chironomidae sp.	0	0	0	0	2770	0	2770	462	0.33
Corophium anenarium	0	0	0	500	500	3200	4200	700	0.50
Corophium lacusta	0	0	0	0	0	8	8	1.3	0.001
Corophium volutator	0	0	0	45	77	2100	2222	370	0.27
Crangon crangon	0	0	0	16	16	22	54	9.0	0.01
Dreissena polymorpha	26	0	0	0	0	0	26	4.3	0.003
Eiseniella tetraedra	0	2900	1170	0	0	0	4070	678	0.5
Enchytraedae	2550	5800	1300	66500	271080	14430	361660	60277	43.4
Eriocheir sinensis	0	0	0	3	0	1	4	0.7	0.0005
Erpobdella octoculata	11	0	0	0	0	0	11	1.8	0.001
Gammarus duebeni	94	124	94	21	34	12	379	63	0.05
Gammarus pulex	0	40	54	0	0	0	94	16	0.01
Gammarus salinus	0	0	0	0	50	74	124	21	0.01
Gammarus zaddachi	848	752	640	214	66	13	2533	422	0.30
Glossiphonia complanata	0	12	1	0	0	0	13	2.2	0.002
Glossiphonia heteroclita	2	3	1	0	0	0	6	1.0	0.001
Helobdella stagnalis	6	7	0	0	0	0	13	2.2	0.002
Heterochaeta costata	0	0	0	17100	30120	2590	49810	8302	5.97
Hirudinae sp.	6	0	0	0	0	0	6	1.0	0.001
Hydrobia jenkinsi	0	52	0	28	40	50	170	28.3	0.02
Hydrobia neglecta	0	0	0	8	22	30	60	10.0	0.01
Hydrobia ulvae	0	0	0	0	0	1200	1200	200	0.14
Limnodrilus cervix	0	4640	325	0	0	0	4965	828	0.6
Limnodrilus claparedianus	4080	5800	390	0	0	0	10270	1712	1.2
Limnodrilus hoffmeisteri	7650	18560	780	34200	10040	4440	75670	12612	9.1
Limnodrilus variegatus	0	1740	260	0	0	0	2000	333	0.2
Lumbriculus variegatus	0	1740	0	0	60240	5550	67530	11255	8.1
Lymnaea peregra	51	0	0	0	58	4	113	18.8	0.01
Lymnaea truncatula	0	4	0	0	54	24	82	13.7	0.01
Mesopodopsis slabberi	0	0	0	2	4	0	6	1.0	0.001
Monopylepthorus rubroniveus	0	0	0	0	30120	2960	33080	5513	3.97
Mytilus edulis	30	0	0	0	0	0	30	5.0	0.004
Nephtys hombergi	0	0	0	0	7	14	21	3.5	0.003
Nereis diversicolor	0	0	0	7	13	200	220	36.7	0.03
Nereis viren	0	0	0	0	21	0	21	3.5	0.003
Oniscus asellus	0	0	0	0	0	10	10	1.7	0.001
Palaemonetes varians	0	0	0	0	0	8	8	1.3	0.001
Paranais littoralis	0	2900	715	0	0	0	3615	603	0.4
Perinereis cultrfera	0	0	0	0	37	20	57	9.5	0.01
Potamothrix hammoniensis	0	0	0	0	45180	2220	47400	7900	5.7
Psammoryctides barbatus	0	3480	520	26600	0	0	30600	5100	3.7
Scoloplos armiger	0	0	0	0	4	0	4	0.7	0.0005
Thalassodrilus prostatus	0	0	0	20900	0	0	20900	3483	2.5
Theodoxus fluviatilis	4	0	0	0	0	0	4	0.7	0.0005
Tubifex pseudogaster	0	0	0	0	25100	2960	28060	4677	3.4
Tubifex tubifex	10200	8700	1040	0	0	0	19940	3323	2.4
Total Density	4431	59011	7294	190891	505867	44097	811591	135265	100

There were marked variations in benthic invertebrate densities between water bodies, sample sites within water bodies and summer and winter seasons. In summer between species relative macroinvertebrate densities differences were significant ($P < 0.001$) at $P = 0.05$ but between sites differences were not significant ($P = 0.08$) at $P = 0.05$. In the winter between species and sites macroinvertebrate relative densities were significantly different ($P = 0.001$ and 0.02) at $P = 0.05$ respectively.

3.4.1 Total seasonal densities and species richness of benthic invertebrates

The summer and winter invertebrate densities for all the sites sampled are summarised below. Table 3.3 shows the winter and summer sites relative species densities.

Table 3.3 Total relative densities of benthic macroinvertebrates sampled from all sites

Number/ m^{-2}

Site	summer	R	% (S)	winter	R	% (W)	Total (A)	% (A)
Teddington	30512	26	0.34	26586	16	0.21	57098	0.27
Hammersmith	19137	19	0.22	59011	21	0.47	78148	0.37
Battersea	104214	18	1.18	7294	16	0.06	111508	0.52
Greenwich	631110	23	7.14	190891	17	1.54	822001	3.86
Belvedere	407614	29	4.61	505867	27	4.07	913481	4.29
Grays	136040	25	1.54	44097	30	0.35	180137	0.85
Chelsea Creek	1221505	22	13.81	11550402	12	92.91	12772912	60.03
Deptford Creek	1103019	28	12.47	1044	9	0.01	1104375	5.19
Bow Creek	960716	20	10.86	3270	9	0.03	964085	4.53
Barking Creek	1842863	19	20.83	4309	7	0.03	1847233	8.68
Dartford Creek	1602993	17	18.12	877	4	0.01	1603871	7.54
East India Basin	357998	21	4.05	29156	20	0.23	387154	1.82
King George V Basin	13663	17	0.15	2774	15	0.02	16437	0.08
Royal Albert Basin	14300	17	0.16	2838	15	0.02	17138	0.08
Royal Victoria Basin	398026	18	4.50	3835	15	0.03	401861	1.89
Total	8843710	78	100	12432251	64	100	21277439	100

% (S) = as a percentage proportion of summer total
% (w) = as a percentage proportion of winter total
% (A) = as a percentage proportion of annual total
Total (A) = annual sites totals
R = number of species = richness

Mean densities were generally greater for majority of the sites in the summer than in the winter except for Chelsea creek, Hammersmith and Belvedere. Using a two-tailed t-test to compare the summer and winter mean densities revealed that they were not significantly different [($t_{(obs)}(14) = +(0.75)$, at $P = 0.05$]. However, the summer and winter species richness means differences were significantly different [($t_{(obs)}(14) = +3.06$)]. The implications for non significant differences in the seasonal mean densities and the significant differences in the mean species richness are two folds. Firstly, it means that only macroinvertebrate species composition changed between seasons but not the macroinvertebrate densities and secondly, it also implies that fish food availability did not change significantly between seasons but its composition changed.

3.4.2 Teddington

A total of 57098 (0.27% as a percentage of the annual total) individual macroinvertebrates were collected from Teddington site consisting of 30512 in the summer (26 species) and 26586 (16 species) in the winter samples. By far the greatest contribution in terms of numbers comes from oligochaete species. Other fresh water macroinvertebrate species namely *Helobdella stagnalis*, *Glossiphonia heteroclita*, *Glossiphonia complanata*, *Erpobdella testacea*, *Gammarus zaddachi*, *Asellus aquaticus*, Hirudinae sp., *Erpobdella octoculata* and *Dreissena polymorpha* were present. In winter there was an increase in the numbers of the *Gammarus sp*.

3.4.3 Hammersmith

A total of 78148 individuals were collected from Hammersmith; 19137 were collected in summer (19 species) and 59011 (21 species) in winter. Hammersmith contributes 0.37% of the total number of organisms sampled from the 15 sites. Oligochaete species were numerically abundant. However, like Teddington the contribution of freshwater individuals is more evident. Higher values of macroinvertebrate densities were observed in winter samples again due to the very high abundance of *Gammarus* species in this period in the upper reaches of the estuary. These observations on the high numbers of freshwater species in particular *Gammarus sp*, especially *Gammarus Zaddachi* were made by Andrews, (1977), Andrews *et al.* (1992), Benthic Ecology Research Group (1997) and more recently by Attrill (1998) and Attrill *et al* (1999).

3.4.4 Battersea

A total of 111508 individuals were collected in Battersea. Battersea exhibited higher numbers in summer (104214; 18 species) than in winter (7294; 16 species). This was due to lower numbers of oligochaete species in winter than in the summer. As a percentage of the total number of organisms sampled from the 15 sites Battersea contributed 0.52%. Apart from *Gammarus sp* and oligochaete species there was a general absence of freshwater species in this site in both winter and summer.

3.4.5 Greenwich

An increase in the numbers of individuals was observed in the mid estuarine sites. These observations were also made by Andrews, (1977), Andrews *et al.* (1992), The Benthic Ecology Research Group (1997) and recently by Attrill (1998) and Atrill *et al* (1999). This high number of individuals was due to the increase in the number of mud dwelling worms (oligochaete and polychaete species). A total of 822001 individuals were collected from this site: 631110 in summer (23 species) and 190891 in winter

(17 species). For both summer and winter, freshwater species were not very important in this site. Instead, the estuarine species *Hydrobia* sp, *Balanus amphitrite, Balanus improvisus, Corophium sp, Crangon crangon, Palaemonetes varians, Nereis diversicolor, Nephtys hombergi* and salinity tolerant oligochaetes were more important. These typically brackish water species are typical of this zone (Andrews, (1977; Andrews *et al.*, 1992; The Benthic Ecology Group, 1994; Attrill, 1998; Power *et al.*, 1999). Greenwich was characterised by the presence of a heterogeneous habitat including mudflats which harbour oligochaetes and polychaete worms. Greenwich contributed 3.86% of the summer and winter total macroinvertebrate organisms. There was a general drop in the populations of these species in winter at the site.

3.4.6 Belvedere

This site had a similar species composition with Greenwich and it lies immediately downstream of Beckton and Crossness sewage outfalls; 913481 individuals collected in the two seasons. There were fewer individuals in summer (407614; 29 species) than in the winter (505867; 27 species). This seasonal difference was brought about by increases in numbers of oligochaete species in the winter period. Belvedere contributed 4.29% of the total number of organisms sampled during winter and summer from the 15 sites.

3.4.7 Grays

Grays yielded fewer individuals than the previous mid estuary sites with a total collection of 180137 individuals. There was a marked difference in the number of individuals between summer (136040 individuals; from 25 species) and winter (44097 individuals; from 30 species). Mud dwelling and salinity tolerant species such as hydrobia, polychaete, corophium, and oligochaete species dominated the invertebrate community. The contribution of Grays to the total number of organisms annually from the 15 sites was 0.85%.

3.4.8 Taxonomic composition of benthic invertebrates

Table 3.1, 3.2 , 3.4, 3.5 and 3.7 are the primary data for benthic macroinvertebrates collected from the main river, dock basins and creeks sites during the summer of 2002. Eighty species were identified in all the sites surveyed. It is indicative from Table 3.1 and 3.2 that, apart from the overshadowing effects of oligochaete species numbers the taxonomic composition of sites along the upper estuary i.e. Teddington, Hammersmith and Battersea was mainly of freshwater macroinvertebrates fauna of upstream origin namely, *Helobdella stagnalis, Glossiphonia heteroclita, Glossiphonia complanata, Erpobdella testacea, Gammarus zaddachi, Asellus aquaticus* etc. On the other hand the taxonomic composition of sites along the mid estuary was made up of a mixture of macroinvertebrate species that originated from both ends of the estuary i.e. from the freshwater end and the marine end e.g., *Gammarus zaddachi, Asellus aquaticus, Gammarus duebeni, Gammarus pulex* and some Oligochaete species (for the freshwater members) and *Carcinus maenas, Balanus amphitrite, Balanus improvisus, Nereis viren, Nereis diversicolor, Perenereis cultrifera, Nephtys hombergi, Corophium locusta* (for the marine representatives).

The Taxonomic composition of the dock basins appear to have gone through 'a natural sieving process.' The majority of the macroinvertebrates organisms originate from the mid estuary but epibenthic species that are adapted to living on hard substrate and in environments that lack habitat heterogeneity predominate. These are organisms that adhere to the concrete walls utilising water currents they generate to filter and obtain food e.g., *Victorella pavida, Balanus amphitrite, Balanus improvisus* and *Sabellaria alveolata.* Some organisms utilise the filamentous algal beds and dead reefs on the surface of the walls as substrates or nests e.g., *Jaera nordmanni, Jaera albifrons, Palaemonetes varians, Crangon crangon* and the *Gammarus sp.* The creeks taxa are mostly oligochaete and polychaete worms that inhabit the mud flats of varying compactness and age. The fresh water species found in the creeks environment were collected from the central channels whose origin was the upstream tributaries behind them. The dominant species collected from the different sites and their relative proportions are discussed in later sections.

Overview of the species densities along the main river

Seasonal variation of the total abundance of macroinvertebrates was observed with somewhat lower values being found in winter except for Hammersmith and Belvedere sites which had higher observed winter population densities. Teddington, Battersea, Greenwich, and Grays all showed higher summer population densities. The total number of benthic macrofaunal organisms collected in winter from the upper and middle Thames Estuary was 833728 from which 54 species were identified including 17 oligochaete species. 1328627 individuals were collected in summer from which 62 species were identified. The number of oligochaete species was unchanged at 17.

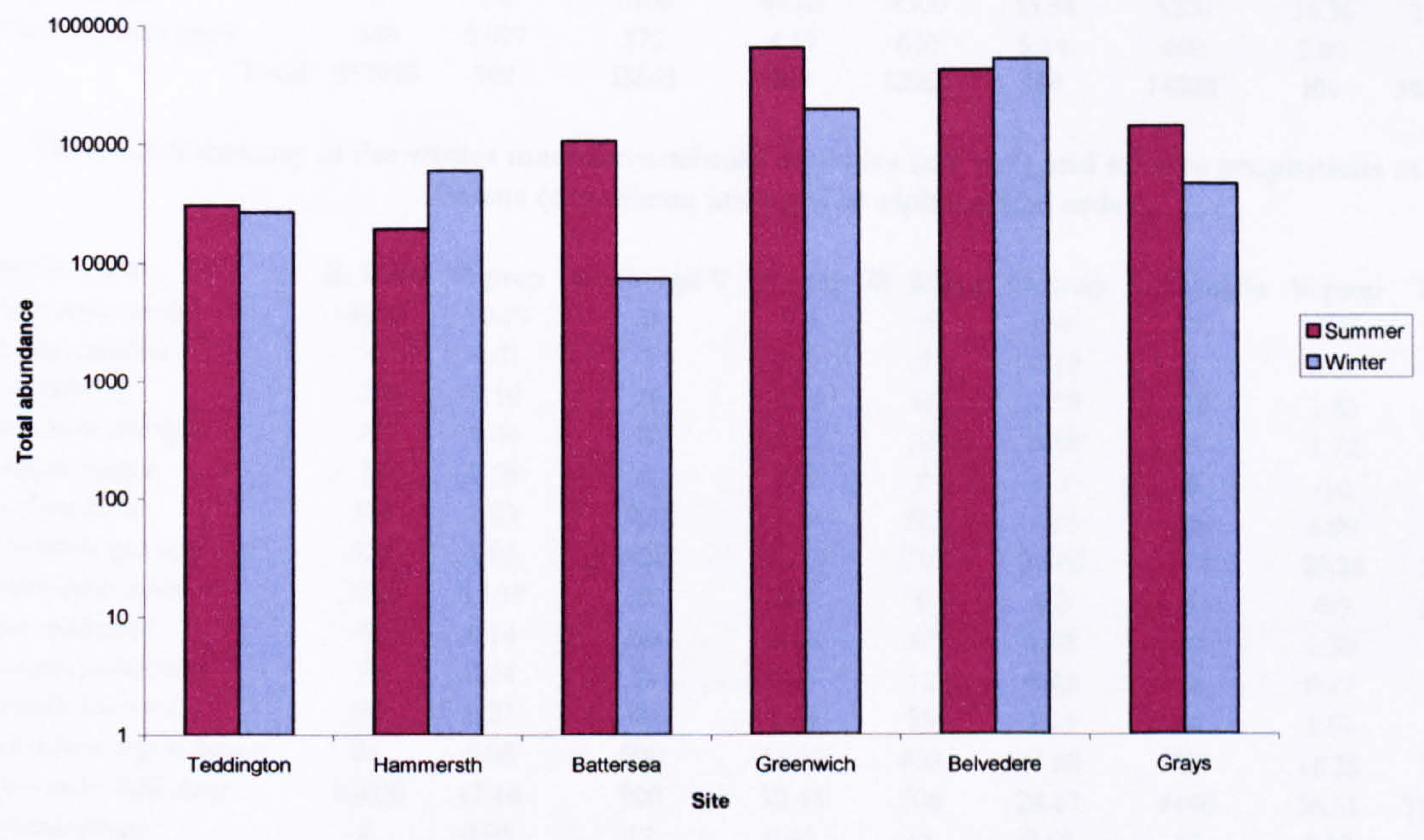
By percentage proportion the most frequent and abundant organisms in summer belong to the group Oligochaeta (97.58%) and the families Corophiidae (1.85%), Gammaridae (0.067) and Polychaeta (0.08%) consisting of three species namely *Nereis diversicolor, Perinereis cultrifera* and *Nephtys hombergi.* The families Gammaridae, Corophiidae, Lumbriculidae, Tubificidae and Enchytraeidae were well represented through out the upper and the middle estuary and were present in both winter and summer seasons in the reaches of these ecological zones. In the mid estuary, in addition to Gammaridae, Corophiidae, Polychaeta and Oligochaeta, the families Balanidae, Crangonidae, Palaemonidae, and Hydrobiidae were abundant and present in both winter and summer.

In winter the Oligochaete species account for 98.23% of the total number of organisms. The family Gammaridae accounted for 0.38% and Corophiidae 0.77% of the total community. In sites of the upper reaches of the estuary namely: Teddington, Hammersmith and in Battersea the families Glossiphoniidae and Asellidae were present.

The overall abundance of Gammaridae, Oligochaeta, Corophiidae, Nereidae, Balanidae, Crangonidae and Palaemonidae populations in the middle estuary suggests that species in these groups play a key role in the ecosystem. . The group Oligochaetes were very strongly represented in terms of the number of species (a total of 17 species) and number of individuals.

Total macrofaunal abundance is plotted in (Figure 3.1). Despite seasonal variation and the possible bias introduced by the sampling methods, a pattern of distribution through the 6 sites was clear. Macrobenthofauna was more abundant in Greenwich and Belvedere sites; sites in the brackish water reaches situated close to the Becton and Crossness sewage discharges. In Teddington, Hammersmith and Battersea there were clearly lower densities.

Figure 3.1 Log10 scale plot of the winter and summer macroinvertebrate densities of sites along the main river



Additional habitats

Macroinvertebrate results for the docks and creeks are now presented, starting with the docks. Table 3.4 and 3.5 show the densities (individuals m^{-2}) of macroinvertebrate species sampled from the dock basins in the summer and winter of 2002 respectively.

Table 3.4 Summary of the summer macroinvertebrate densities (no. m^{-2})and relative proportions at the Dock Basins (organisms arranged in alphabetical order).

Species/Dock site	E. India	% prop	K. George V	% prop	R. Albert	% prop	Q. Victoria	% prop	Total	% Prop.
Amphicaeta sannio	43000	12.01	0	0.0	0	0.00	0	0.00	43000	10.80
Anurida Maritima	18	0.005	0	0.0	0	0.00	12	0.08	30	0.01
Asselus aquaticus	8	0.002	10	0.07	12	0.10	14	0.10	44	0.01
Balanidae sp	34	0.009	38	0.28	24	0.20	62	0.43	158	0.04
Branchiura sowerbyi	0	0.0	452	3.31	400	3.32	600	4.20	1452	0.36
Chironomidae sp	148	0.041	24	0.18	32	0.27	12	0.08	216	0.05
Crangon crangon	780	0.218	154	1.13	128	1.06	22	0.15	1084	0.27
Enchytraedae	0	0.0	600	4.39	750	6.22	702	4.91	2052	0.52
Gammarus zaddachi	320	0.089	332	2.43	284	2.35	300	2.10	1236	0.31
Heterochaeta costata	34000	9.50	0	0.0	0	0.00	0	0.00	34000	8.54
Ischnura elegans	3	0.001	0	0.0	0	0.00	0	0.00	3	0.001
Jaera nordmanni	4	0.001	53	0.39	42	0.35	10	0.07	109	0.03
Leucophytia bidentata	66	0.018	62	0.45	18	0.15	188	1.31	334	0.08
Limnodrilus claparedianus	0	0.0	2140	15.66	1600	13.26	2200	15.38	5940	1.49
Limnodrilus hoffmeisteri	250000	69.8	2900	21.23	3700	30.67	4400	30.77	261000	65.57
Lymnaea pereger	21	0.006	46	0.34	32	0.27	36	0.25	135	0.03
Nereis diversicolor	14	0.004	0	0.00	0	0.00	0	0.00	14	0.004
Palaemonetes varians	180	0.050	88	0.64	60	0.50	64	0.45	392	0.10
Petrobius brevistylis	24	0.007	0	0.0	0	0.00	0	0.00	24	0.01
Sabellaria alveolata (reefs)	4	0.001	10	0.07	3	0.02	6	0.04	23	0.01
Sphaeroma hookeri	22	0.006	82	0.60	60	0.50	72	0.50	236	0.06
Symptrum sanguineum	4	0.001	0	0.0	0	0.00	0	0.00	4	0.001
Thalassodrilus prostatus	29000	8.10	0	0.0	0	0.00	0	0.00	29000	7.29
Tubifex tubifex	0	0.0	6100	44.65	4300	35.64	5200	36.36	15600	3.92
Victorella pavida (reefs)	348	0.097	572	4.19	620	5.14	400	2.80	1940	0.49
Total	357998	100	13663	100	12065	100	14300	100	398026	100

Table 3.5 Summary of the winter macroinvertebrate densities (no. m^{-2}) and relative proportions at the Dock Basins (organisms arranged in alphabetical order).

Species/site	E. India	% prop	K. George V	% prop	R. Albert	% prop	R. Victoria	% prop	Total	% Prop
Amphicaeta sannio	3000	10.29	0	0.0	0	0.0	*0*	0.0	3000	7.77
Asselus aquaticus	*4*	0.01	3	0.11	*5*	0.18	*3*	0.08	15	0.04
Balanidae sp	30	0.10	26	0.94	62	2.18	70	1.83	188	0.49
Branchiura sowerbyi	*12*	0.04	10	0.36	*25*	0.88	*66*	1.72	113	0.29
Crangon crangon	*18*	0.06	0	0.00	*0*	0.0	*0*	0.0	18	0.05
Enchytraedae	*300*	1.03	200	7.21	*225*	7.93	*230*	6.00	955	2.47
Gammarus zaddachi	*300*	1.03	420	15.14	*710*	25.02	*777*	20.26	2207	5.72
Heterochaeta costata	3900	13.38	0	0.0	0	0.0	*0*	0.0	3900	10.10
Jaera nordmanni	*40*	0.14	60	2.16	*52*	1.83	*50*	1.30	202	0.52
Leucophytia bidentata	70	0.24	16	0.58	12	0.42	18	0.47	116	0.30
Limnodrilus cervix	80	0.27	40	1.44	55	1.94	*64*	1.67	239	0.62
Limnodrilus claparedianus	*24*	0.08	500	18.02	*400*	14.09	*700*	18.25	1624	4.21
Limnodrilus hoffmeisteri	12000	41.16	900	32.44	700	24.67	*1400*	36.51	15000	38.86
Lymnaea pereger	8	0.03	12	0.43	18	0.63	16	0.42	54	0.14
Nereis diversicolor	42	0.14	0	0.0	0	0.0	0	0.0	42	0.11
Palaemonetes varians	*5*	0.02	0	0.00	*0*	0.0	*0*	0.0	5	0.01
Sabellaria alveolata (reefs)	3	0.01	3	0.11	6	0.21	5	0.13	17	0.04
Sphaeroma hookeri	*20*	0.07	62	2.24	*72*	2.54	*66*	1.72	220	0.57
Thalassodrilus prostatus	9000	30.87	0	0.0	0	0.0	*0*	0.0	9000	23.31
Tubifex tubifex	0	0.0	60	2.16	72	2.54	*50*	1.30	182	0.47
Victorella pavida (reefs)	*300*	1.03	462	16.65	*424*	14.94	*320*	8.34	1506	3.90
Total	29156	100	2774	100	2838	100	3835	100	38603	100

3.4.9 The East India Dock Basin

Twenty-one macroinvertebrate species were recorded in the East India dock basin in summer (from 357998 individuals) and 20 species in winter (from 29156 individuals). The contribution of the East India basin to the total number of organisms from the 15 sites was 1.82%. The macro-invertebrate community found in the East India basin was dominated by species of both estuarine and freshwater origin similar to those of the mid estuary such as Oligochaetes species, *Gammarus zaddachi, Crangon crangon, Nereis diversicolor* and *Palaemonetes varians.* The reef forming annelids *Victorella pavida* and bryozoan *Sabellaria alveolata* were also present. There was a very high summer presence of the oligochaete species *Limnodrilus hoffmeisteri.* There was an interesting and unexpected presence of *Petrobius brevistylis* (Thysanura), *Ischnura elegans* (Odonata) and *Anurida maritima* (Collembola). These three species were absent in the Royal Dock basins.

3.4.10 King George V Dock Basin

Table 3.4 and 3.5 show the densities (individuals m^{-2}) of macroinvertebrate species sampled from the basins in the summer and winter of 2002 respectively. In summer 13663 benthic organisms (17 species) were sampled from this basin and 2774 (comprising 15 species) in winter. King George V basin contributes only 0.08% of the total organisms sampled from the 15 sites. Numerically the dominant organisms in the King George V Basin in summer were the oligochaetes comprising the species *Tubifex tubifex* (44.65%), *Limnodrilus hoffmeisteri* (21.23%), *Limnodrilus claparedianus* (15.66%), Enchytraedae (4.39%) and *Branchiura sowerbyi* (3.31). Outside the Oligochaetes species the reef forming tube dwelling worm *Victorella pavida* (4.19%) and the crustaceans *Gammarus zaddachi* (2.43%), *Crangon crangon* (1.13%), *Sphaeroma hookeri* (0.60%), *Jaera nordmanni* (0.39%), *Palaemonetes varians* (0.64%) and *Balanus* sp (0.28) were abundant despite their seemingly low percentages relative to the oligochaete species. Two other species namely *Leucophytia bidentata* (0.45%) and *Lymnaea pereger* (0.34%) were abundant.

Fifteen species were identified in the winter samples. As totals in the samples, there were far less oligochaetes in winter (61.64%) than in summer (89.23%) and the organisms were more evenly distributed in terms of numbers. The dominant species were the oligochaetes *Limnodrilus hoffmeisteri* (32.44), *Limnodrilus claparedianus* (18.02%), Enchytraedae (7.21), *Tubifex tubifex* (2.16%) and *Limnodrilus cervix* (1.44). These were followed by the tube worm *Victorella pavida* (16.65%), the amphipod *Gammarus zaddachi* (15.14%), and other crustaceans namely *Sphaeroma hookeri* (2.24%), *Jaera nordmanni* (2.16%), *Balanus sp* (0.94%) and *Asselus aquaticus* (0.11%). The winter assemblage also include *Leucophytia* *bidentata,*(0.58%), *Lymnaea pereger* (0.43%) and *Sabellaria alveolata* (reefs) (0.11). There was a disappearance of the larger shrimps *Grangon crangon* and *Palaemonetes varians* in winter samples.

3.4.11 Royal Albert Dock Basin

In summer 12065 macroinvertebrate organisms comprising 17 species were collected from the Royal Albert Dock Basin. Well represented in the Royal Albert assemblage were 5 oligochaete species namely: *Tubifex tubifex* (35.64%), *Limnodrilus hoffmeisteri* (30.67%), *Limnodrilus claparedianus* (13.26%), Enchytraedae (6.22%) and *Branchiura sowerbyi* (3.32%). The crustaceans *Gammarus zaddachi* (2.35%), *Crangon crangon* (1.06%), *Palaemonetes varians* (0.50%), *Sphaeroma hookeri* (0.50%), *Jaera nordmanni* (0.35%) and *Balanus* sp (0.20%). Also present in the summer macroinvertebrate assemblage were *Victorella pavida* (reefs) (5.14%), *Sabellaria alveolata* (reefs) (0.02%), *Lymnaea pereger* (0.27%), *Leucophytia bidentata.*(0.15%) and Chironomidae (0.27%).

In winter 2838 individuals from 15 species were collected from the Royal Albert Basin. Six oligochaete species namely: *Limnodrilus hoffmeisteri* (24.67%), *Limnodrilus claparedianus* (14.09%), Enchytraedae (7.93%), *Tubifex tubifex* (2.54%) *Limnodrilus cervix* (1.94%), *Branchiura sowerbyi* (0.88%), were present in the winter macroinvertebrate assemblage. *Gammarus zaddachi* (25.02%) was the dominant species in winter. The annelid *Victorella pavida* (reefs) (14.94%) was abundant. Other crustaceans namely *Sphaeroma hookeri* (2.54%), *Balanidae sp* (2.18%), *Jaera nordmanni* (1.83%) and *Asselus aquaticus* (0.18%) were present. The Royal Albert dock also contributed 0.08% of the total number of summer and winter macroinvertebrates of the 15 sites.

3.4.12 Queen Victoria Dock Basin

Summer samples from the Queen Victoria Dock Basin contained 14300 organisms distributed over 18 species (Table 3.4). Oligochaete species made up 91.62% of the total summer macroinvertebrate community. *Tubifex tubifex* (36.36%) was the dominant Oligochaete species during summer followed by *Limnodrilus hoffmeisteri* (30.77%), *Limnodrilus claparedianus* (15.38%), Enchytraedae (4.91%) and *Branchiura sowerbyi* (4.21%). The Annelid *Victorella pavida* (reefs) (2.80%) and the amphipod crustacean *Gammarus zaddachi* (2.10%) were abundant. Other crustaceans such as *Sphaeroma hookeri* (0.50%), *Palaemonetes varians* (0.45%), Balanidae sp (0.43%) were also present in significant numbers.

Winter samples at the Queen Victoria Dock yielded 3835 macroinvertebrate organisms from which 15 species were identified. Oligochaetes contribute 65.45% of the total number of organisms. The dominant oligochate species was *Limnodrilus hoffmeisteri* (36.51%) and this was followed *Limnodrilus claparedianus* (18.25%), Enchytraedae (6.00%), *Branchiura sowerbyi* (1.72%), *Limnodrilus cervix* (1.67%) and *Tubifex tubifex* (1.30%). *Gammarus zaddachi* (20.26%) was very abundant in the basin during winter but exhibited lower populations in summer (2.10%). Other brackish water crustaceans namely: Balanidae sp (1.83%), *Sphaeroma hookeri* (1.72%) and *Jaera nordmanni* (1.30%) were also present in significant numbers. The fresh water crustacean *Asselus aquaticus* (0.08%) was generally very occasional in all the basins (see Tables 3.4 and 3.5). *Victorella pavida* (reefs) (8.34%) were abundant. *Lymnaea pereger* (0.42%) and *Sabellaria alveolata* (reefs) (0.13%) were also present. The contribution of Queen Victoria basin to the total winter and summer macroinvertebrates of the 15 sites was 1.89%.

An overview of the Royal Docks macroinvertebrate assemblages

Using a two-tailed t-test to compare the summer and winter mean macroinvertebrate densities of the dock basins revealed that they were not significantly different [$(t_{(obs)}(3) = + (1.127)$, at $P = 0.05$]. The main similarities between the three Royal Dock basins for both summer and winter macroinvertebrate dataset were: 1) the Royal Docks are characterised mainly by the presence of macroinvertebrate species adapted to living in brackish water. 2) They also contain organisms adapted to living in hard or stony substrates, mainly living as epibenthos. 3) Oligochaetes species were the dominant organisms at the Royal Dock Basins in terms of numbers, but their abundances were far less than those of the East India Dock Basin, main river or estuarine creeks. 4) Fewer species of oligochaetes are present as well compared to 17 in most main river sites.

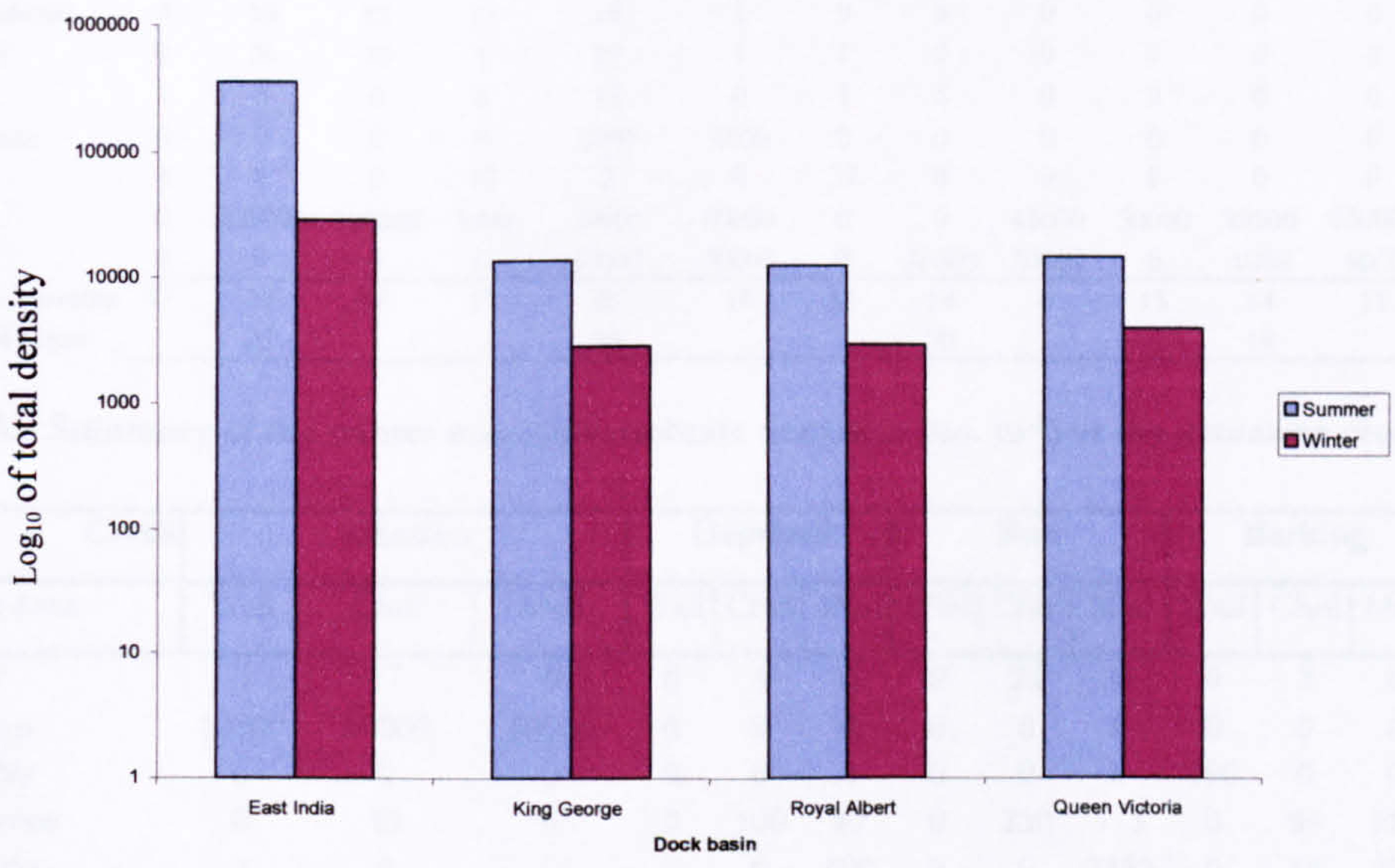
6) *Victorella pavida* and *Sabellaria alveolata* species that form reef communities were very abundant in the Royal Docks and appeared to be restricted in the impounded bedrock substrate environments of the dock basins and this was no surprise. *V. pavida* reefs or crusts will form on bedrock substrata though this does not preclude their formation on other substrata (Hiscock, 1991.). Several sources suggest that substrate is not necessary for formation of *Sabellaria* crusts and reefs, though a somewhat firm substratum is presumably required. Rees and Dare (1993) describe habitat/ distribution as being typically on shell (especially oyster valves), sandy gravel or rocky substrata with moderate to strong tidal flow. Larsonneur (1994) reported that *Sabellaria* dominated communities were present on rock/pebble bottoms in the Bay of Mont St Michel. He also reported that sand masons *Lanice conchilega* could sufficiently stabilise sand to allow colonisation by *S. alveolata*. It can be speculated that the same process might be possible with *V. pavida* too, since *S. alveolata* and *V. pavida* are sometimes found together (e.g. Foster-Smith *et al.*, 1997) and extensive *Sabelaria* colonies are known to occur in essentially sandy areas; this has not been demonstrated, however in this study.

7) The fresh water crustacean *Asellus aquaticus* was very occasional in all seasons. 8) The brackish water isopods *Sphaeroma hookeri*, *Jaera nordmanni*, the decapods *Palaemonetes varians*, *Crangon crangon* and the Thoracica Balanidae species were well represented and well distributed throughout the three Royal dock basins in summer. 8) *Gammarus Zaddachi*, was present through out the year though in reduced number during summer.

There were seasonal differences in the Royal Docks species assemblages. In summer the King George, Royal Albert and Queen Victoria Basins had 17, 17 and 18 macroinvertebrate species respectively. In winter samples collected from the three basins all contained 15 species each. There was a general disappearance of *Palaemonetes varians* and *Crangon crangon* from the winter Royal Docks macroinvertebrate datasets.

Figure 3.2 is a Log_{10} scale plot of the winter and summer total densities of macroinvertebrate fauna collected from the dock basins. The graph highlights three main features. Firstly, the East India Dock exhibits a higher number of organisms in both summer and winter than the Royal Docks. Secondly, the summer samples exhibited higher numbers of organisms than the winter samples and thirdly there were very small differences in the total number of organisms between the Royal Docks for both summer and winter datasets.

Figure 3.2 Log10 scale plot of the winter and summer macroinvertebrate densities of the Dock Basins



3.4.13 The Estuarine Creeks

Table 3.6 and 3.7 show the densities (number m^{-2}) of macroinvertebrate fauna for 5 estuarine creeks namely Chelsea, Deptford, Bow, Barking and Dartford Creeks in summer and winter 2002. Tables 3.6 and 3.7 indicate the number of species identified from the different areas of the creeks and the total number of individuals from each species from each creek.

Table 3.6 Summary of the summer macroinvertebrate densities (no. m^{-2}) at the estuarine creeks in 2002

Creek	Chelsea Creek			Deptford creek			Bow creek			Barking creek			Dartford creek		
Species	wall	chnl	mud	Wall	Chnl	Mud	Wall	Chnl	Mud	Wall	Chnl	Mud	Wall	Chnl	Mud
Amphicaeta sannio	0	0	0	1000	100000	100000	0	0	430000	50000	150000	200000	60000	11000	300000
Anurida maritima	0	200	201	32	0	0	40	0	0	19	0	0	14	0	0
Asellus aquaticus	0	12	20	2	32	0	2	14	0	1	3	0	1	0	0
Assiminea grayana	8	0	0	16	0	0	20	0	0	12	0	0	2	0	0
Branchiura sowerbyi	5000	120000	235000	0	2000	20000	0	0	0	0	0	0	0	0	0
Chironomidae	10	10	14	12	20	0	34	12	0	32	9	0	21	12	0
Cordylophora caspia	220	78	0	280	54	0	340	22	0	190	0	0	20	0	0
Corophium arenarium	0	52	11	0	229	588	0	380	763	0	884	982	0	542	431
Corophium volutator	0	88	28	0	414	814	0	232	3432	0	344	892	0	654	876
Enchytraedae	2000	5000	13000	60000	100000	140000	0	0	0	20000	300000	420000	100000	200000	300000
Eriocheir sinensis	0	3	1	0	3	0	0	0	0	0	0	0	0	0	0
Gammarus zaddachi	6	348	43	18	93	0	20	12	1	8	16	0	23	17	5
Glossiphonia complanata	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0
Helobdella stagnalis	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0
Heterochaeta costata	0	0	0	0	22000	60000	0	9000	50000	0	2000	7000		9000	50000
Limnodrilus cervix	0	0	0	800	14000	19200	0	0	0	0	0	0	0	0	0
Limnodrilus claparedianus	400	4000	15600	0	45000	45000	0	0	0	10000	40000	70000	0	20000	60000
Limnodrilus hoffmeisteri	0	50000	270000	10000	30000	90000	12000	70000	288000	0	0	0	0	0	0
Limnodrilus variegatus	0	0	0	1000	4000	7000	0	0	0	2000	5000	33000	0	0	50000
Lumbriculus variegatus	0	0	0	0	400	1600	0	0	0	0	2000	4000	0	0	0
Lymneae peregra	0	30	10	0	18	0	2	6	0	0	0	0	0	0	0
Nereis diversicolor	0	0	0	2	318	978	12	888	2432	80	433	2948	13	5682	668
Pisidium spp	0	2	0	0	4	1	0	1	0	0	0	0	0	0	0
Potamopyrgus antipodarum	2	10	12	12	18	1	9	5	0	0	0	0	0	0	0
Potamopyrgus jenkisi	0	20	33	1	19	1	1	0	0	0	0	0	0	0	0
Sphaeroma bookery	1	6	0	6	12	0	1	3	0	2	0	0	0	0	0
Thalassodrilus prostatus	0	0	0	0	2000	4000	0	0	0	0	0	0	0	0	0
Tipulidae	3	0	0	19	2	0	32	0	0	8	0	0	12	0	0
Tubifex tubifex	0	220000	300000	3000	20000	80000	0	0	43000	50000	89000	250000	40000	100000	290000
Tubificoides benedii	0	0	0	0	18000	50000	0	20000	30000	0	1000	8000	0	1000	4000
No. species	*11*	*20*	*15*	17	26	18	13	14	9	15	14	11	11	12	11
No. species all areas		*22*			28			20			19			17	

Table 3.7 Summary of the winter macroinvertebrate densities (no. m^{-2}) at the estuarine creeks in 2002

Creek	Chelsea			Deptford			Bow			Barking			Dartford		
species/creek area	Wall	Chnl	Mud	Wall	Chnl	Mud	Wall	Chnl	Mud	Wall	Chnl	Mud	Wall	Chnl	Mud
Asellus aquaticus	0	17	0	0	3	0	0	24	0	0	3	0	0	0	0
Branchiura sowerbyi	10000	40000	60000	0	0	0	0	0	0	0	0	0	0	0	0
Cordylophora caspia	0	0	0	0	0	0	0	0	0	190	0	0	0	0	0
Corophium arenarium	0	12	0	0	100	40	0	230	173	0	84	982	0	52	40
Corophium volutator	0	0	0	0	0	400	0	0	2452	0	34	892	0	94	86
Enchytraedae	10000	30000	70000	0	0	0	0	0	0	0	0	0	0	0	0
Eriocheir sinensis	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Gammarus zaddachi	0	322	0	0	194	0	0	122	0	0	1600	0	23	17	5
Helobdella stagnalis	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Limnodrilus claparedianus	0	300000	1400000	0	0	0	0	0	0	0	0	0	0	0	0
Lymnaea peregra	0	6	0	0	28	0	0	16	14	0	0	0	0	0	0
Nereis diversicolor	0	0	0	0	80	140	0	10	210	0	180	294	0	300	260
Pisidium sp	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Potamopyrgus antipodarum	0	0	0	4	6	1	3	1	0	0	0	0	0	0	0
Potamopyrgus jenkinsi	0	0	0	0	12	8	0	0	0	0	0	0	0	0	0
Psammoryctides barbatus		860000	2000000	0	0	0	0	0	0	0	0	0	0	0	0
Sphaeroma hookeri	34	8	0	16	12	0	1	13	0	6	44	0	0	0	0
Tubifex pseudogaster	10000	700000	6000000	0	0	0	0	0	0	0	0	0	0	0	0
No. species	4	12	5	2	8	5	2	8	4	2	6	3	1	4	4
No. species all areas		12			9			9			7			4	

Tables 3.8 and 3.9 show the total species densities and their percentage proportions in summer and winter samples respectively. Thirty species were identified from the creeks summer samples and 18 from the winter samples. An estimated 6,580,096 organisms were collected from the five creeks in summer, of which 12 species and 6,550,000 individuals (99.54%) were Oligochaetes and 18 species [30096 (0.46%)] were organisms of other taxa. In winter 11499902 organisms from 18 species were collected of which 11490000 (99.91%) from 5 sub-species were oligochaetes. The total densities of the respective creeks, their walls, central channels and mudflats were analysed in the following sections. The densities of the creek walls, central channels and mudflats were also expressed as percentages of the total seasonal creek macroinvertebrate densities to express the proportion of organisms' contribution by the areas of the creeks.

Table 3.8 The summer combined total species densities (no. m^{-2}) of the creeks wall, mud and central channels

species/summer	Chelsea	% Prop	Deptford	% prop	Bow	% prop	Barking	% prop	Dartford	% prop	All sites	% prop
Amphicaeta sannio	0	0.0	250000	22.66	430000	44.75	400000	21.70	370000	23.08	1450000	21.54
Anurida maritima	401	0.03	32	0.003	40	0.004	19	0.001	14	0.0009	506	0.01
Asellus aquaticus	32	0.003	34	0.003	16	0.002	4	0.0002	1	6E-05	87	0.001
Assiminea grayana	8	0.001	16	0.001	20	0.002	12	0.001	2	0.0001	58	0.001
Branchiura sowerbyi	340000	27.81	22000	1.99	0	0	0	0.0	0	0	362000	5.38
Chironomidae	34	0.003	32	0.003	46	0.005	41	0.002	33	0.002	186	0.003
Cordylophora caspia	298	0.02	334	0.03	362	0.04	190	0.01	20	0.001	1204	0.02
Corophium arenarium	63	0.01	817	0.07	1143	0.12	1866	0.10	973	0.06	4862	0.07
Corophium volutator	116	0.01	1228	0.11	3664	0.38	1236	0.07	1530	0.10	7774	0.12
Enchytraedae	20000	1.64	300000	27.19	0	0	800000	43.41	600000	37.43	1720000	25.55
Eriocheir sinensis	4	0.0003	3	0.0003	0	0	0	0.0	0	0	7	0.0001
Gammarus zaddachi	397	0.03	111	0.01	33	0.003	24	0.001	45	0.003	610	0.01
Glossiphonia complanata	15	0.001	0	0.0	0	0	0	0.0	0	0	15	0.0002
Helobdella stagnalis	8	0.001	0	0.0	0	0	0	0.0	0	0	8	0.0001
Heterochaeta costata	0	0.0	82000	7.43	59000	6.14	72000	3.91	59000	3.68	272000	4.04
Limnodrilus cervix	0	0.0	34000	3.08	0	0	0	0.0	0	0	34000	0.51
Limnodrilus claparedianus	20000	1.64	90000	8.16	0	0	120000	6.51	80000	4.99	310000	4.60
Limnodrilus hoffmeisteri	320000	26.18	130000	11.78	370000	38.51	0	0.0	0	0	820000	12.18
Limnodrilus variegatus	0	0.0	12000	1.09	0	0	40000	2.17	50000	3.12	102000	1.52
Lumbriculus variegatus	0	0.0	2000	0.18	0	0	6000	0.33	0	0	8000	0.12
Lymneae peregra	40	0.003	18	0.002	8	0.0008	0	0.0	0	0	66	0.001
Nereis diversicolor	0	0.0	1298	0.12	3332	0.35	3461	0.188	6363	0.40	14454	0.21
Pisidium spp	2	0.0002	5	0.0005	1	0.0001	0	0.0	0	0	8	0.0001
Potamopyrgus antipodarum	24	0.002	31	0.003	14	0.001	0	0.0	0	0	69	0.001
Potamopyrgus jenkisi	53	0.004	21	0.002	1	0.0001	0	0.0	0	0	75	0.001
Sphaeroma bookery	7	0.001	18	0.002	4	0.0004	2	0.0001	0	0	31	0.0005
Thalassodrilus prostatus	0	0.0	6000	0.54	0	0	0	0.0	0	0	6000	0.09
Tipulidae	3	0.0002	21	0.002	32	0.003	8	0.0004	12	0.0007	76	0.001
Tubifex tubifex	520000	42.54	103000	9.34	43000	4.48	389000	21.11	430000	26.82	1485000	22.06
Tubificoides benedii	0	0.0	68000	6.16	50000	5.20	9000	0.49	5000	0.31	132000	1.96
Total	1221505	100	1103019	100.0	960716	100.0	1842863	100	1602993	100.0	6731096	100

Table 3.9 The winter combined total species densities of the creeks wall, mud and central channels

species/winter	Chelsea	% prop	Deptford	% prop	Bow	% prop	Barking	% prop	Dartford	% prop	All sites	% prop
Asellus aquaticus	17	0.00015	3	0.29	24	0.73	3	0.07	0	0	47	0.0004
Branchiura sowerbyi	110000	0.95235	0	0	0	0.0	0	0	0	0	110000	0.95
Cordylophora caspia	0	0	0	0	0	0.0	190	4.41	0	0	190	0.002
Corophium arenarium	12	0.0001	140	13.41	403	12.32	1066	24.74	92	10.49	1713	0.01
Corophium volutator	0	0	400	38.31	2452	74.98	926	21.49	180	20.52	3958	0.03
Enchytraedae	110000	0.95235	0	0	0	0.0	0	0	0	0	110000	0.95
Eriocheir sinensis	1	8.7E-06	0	0	0	0.0	0	0	0	0	1	0.00001
Gammarus zaddachi	322	0.00279	194	18.58	122	3.73	1600	37.13	45	5.13	2283	0.02
Helobdella stagnalis	2	1.7E-05	0	0	0	0.0	0	0	0	0	2	0.00002
Limnodrilus claparedianus	1760000	15.2376	0	0	0	0.0	0	0	0	0	1760000	15.23
Lymnaea peregra	6	5.2E-05	28	2.68	30	0.92	0	0	0	0	64	0.001
Nereis diversicolor	0	0	220	21.07	220	6.73	474	11.0	560	63.85	1474	0.01
Pisidium sp	0	0	0	0	1	0.03	0	0	0	0	1	0.00001
Potamopyrgus antipodarum	0	0	11	1.05	4	0.12	0	0	0	0	15	0.0001
Potamopyrgus jenkinsi	0	0	20	1.92	0	0.0	0	0	0	0	20	0.0002
Psammoryctides barbatus	2860000	24.761	0	0	0	0.0	0	0	0	0	2860000	24.74
Sphaeroma hookeri	42	0.00036	28	2.68	14	0.43	50	1.16	0	0	134	0.001
Tubifex pseudogaster	6710000	58.0932	0	0	0	0.0	0	0	0	0	6710000	58.05
Total	11550402	100	1044	100	3270	100.00	4309	100	877	100	11559902	100.00

3.4.14 Chelsea Creek

In summer 1221505 organisms were collected from the Chelsea Creek spread over 22 species; 1240000 (99.87%) of these organisms are oligochaetes spread over 5 species. Locally 7651 (0.61%; 11 species) organisms were collected from the creek wall, 399881 (32.20%; 20 species) from the central channel and 833973 (67.17%; 15 species) from the mud flats. The most abundant species in summer in the Chelsea Creeks were: *Tubifex tubifex* (42.54%) followed by *Branchiura sowerbyi* (27.81%), *Limnodrilus hoffmeisteri*, Enchytraedae and *Limnodrilus claparedianus* all of which were oligochaetes. The species *Anurida maritima* , *Gammarus zaddachi* and *Cordylophora caspia* were numerically abundant.

In winter 11550402 organisms (12 species) were collected from Chelsea Creek of which 11490000 (99.99%) were oligochaete worms belonging to only 5 sub-species. Four species from 30034 (0.26%) individuals were identified from the creek wall, 1930368 (12 species; 16.79%) from the central channel and 9530000 (5 species; 82.92%) from the mud flats. Chelsea contributed the highest number of organisms (60.03% of the total summer and winter for the 15 sites). The most abundant species in winter included *Tubifex pseudogaster* (58.09%) followed by *Psammoryctides barbatus* (24.76%) and *Limnodrilus claparedianus*. Non oligochaete species were very few. The most abundant species amongst the non oligochaete species were *Gammarus zaddachi*. and *Sphaeroma hookeri*.

3.4.15 Deptford Creek

In summer 1103019 organisms belonging to 28 species were identified from Deptford Creek. Like Chelsea Creek most of the individuals collected were Oligochaete worms (1050000 individuals belonging to 12 sub-species; 99.62%). From the creek walls 76200 organisms (17 species; 7.23%) were collected, 358686 (26 species; 34.03%) from the central channels and 619183 (18 species; 58.74%) from the mud flats. The rest of 4019 organisms belonged to 16 other species. The proportion of organisms as a percentage of the summer and winter total for the 15 sites was 5.19%. Enchytraedae sp were the most abundant species in summer (27.19%) followed by *Amphicaeta sannio* (22.66%), *Limnodrilus hoffmeisteri* (11.78%), *Tubifex tubifex* (9.34%), *Limnodrilus claparedianus* (8.16%), *Heterochaeta costata* (7.43%), *Tubificoides benedii* (6.16%), *Limnodrilus cervix* (3.08%) and *Limnodrilus variegates* (1.09). The family Corophidae was well represented with the following species *Corophium arenarium* and *Corophium volutator.* The species *Cordylophora caspia* was also well represented.

There was a marked reduction in both numbers and diversity in winter. In winter 1044 macroinvertebrate organisms belonging to 9 species were collected from Deptford Creek. Of this number no oligochaete species were identified, 20 (1.92%) organisms belonging to 2 species were sampled from the creek walls, 435 individuals (41.67%) belonging to 8 species from the central channel and 589 individuals (56.42%) belonging to 5 species were collected from the mud flats. The most abundant species in winter were *Corophium volutator* (38.31%), *Nereis diversicolor* (21.07%), *Gammarus zaddachi* (18.58%), *Corophium arenarium* (13.41%), *Sphaeroma hookeri* (2.68%), *Lymnaea peregra* (2.68%), *Potamopyrgus jenkinsi* (1.92%) and *Potamopyrgus antipodarum* (1.05%). Crustacea was the most abundant family in winter.

3.4.16 Bow Creek

In the summer 960716 organisms from 20 species were sampled from Bow Creek and of these 952000 (99.09%) were oligochaete species belonging to 5 sub-species were identified. The creek walls samples contained 12513 organisms (1.30%) belonging to 13 species, 100575 organisms (10.47%) belonging to 14 species were sampled from the central channel and 847628 organisms (88.23%) belonging to 9 species were sampled from the mud flats. *Amphicaeta sannio* (44.75%), *Limnodrilus hoffmeisteri* (38.51%), *Heterochaeta costata* (6.14%), *Tubificoides benedii* (5.20%) and *Tubifex tubifex* (4.48%) (all oligochaete worms) were the most abundant organisms in the Bow Creek macroinvertebrate samples in summer. The most abundant non-oligochaete species in summer were *Corophium volutator* (0.38%), *Nereis diversicolor* (0.35%), *Corophium arenarium* (0.12%), and *Cordylophora caspia* (0.04%).

In winter 3270 macroinvertebrate organisms belonging to 9 species were sampled from Bow Creek. No oligochaete worms were identified in winter samples. From the creek wall 4 organisms (0.12%)

belonging to 2 species were sampled. Samples from the central channels contained 417 organisms (12.75%) belonging to 8 species. Samples from the mud flat contain 2849 organisms (87.12%) belonging to 4 species. Bow Creek contributed 4.53% of the total organisms. In winter the most abundant organisms were *Corophium volutator* (74.98%), *Corophium arenarium* (12.32%), *Nereis diversicolor* (6.73%) and *Gammarus zaddachi* (3.73%).

3.4.17 Barking Creek

From the Barking Creek 1842863 organisms belonging to 19 species were collected in summer. Of these 1713000 organisms (99.60) were oligochaete worms. The creek walls samples contained 132352 (7.70%), organisms belonging to 15 species the central channel 590689 organisms (14 species; 34.35%) and the mud flats 996822 organisms (57.95%) belonging to 11 species. In the summer the most abundant species were Enchytraedae (43.1%), *Amphicaeta sannio* (21.70%), *Tubifex tubifex* (21.11%) *Limnodrilus claparedianus* (6.51%), *Heterochaeta costata* (3.91%) and *Limnodrilus variegates* (2.17%). These dominant species were all oligochaete worms.

A total of 4309 organisms belonging to 7 species were collected from Barking Creek in winter. No oligochaete species were identified. There were 196 organisms (4.55%) from the creek wall (2 species), 1945 from the central channel (6 species; 45.14%) and 2168 from the mud flats (3 species; 50.31%). Barking Creek contributed 8.68% of the total macroinvertebrate organisms. The crustaceans *Gammarus zaddachi* (37.13%), *Corophium arenarium* (27.74%) and *Corophium volutator* (21.49%) were the most abundant species in winter in Barking Creek. The polychaete worm *Nereis diversicolor* (11.0%) was the most abundant non-crustacean species. *Cordylophora caspia* (4.41%) and *Sphaeroma hookeri* (1.16%) were also well represented.

3.4.18 Dartford Creek

Summer samples contained a total of 1602993 organisms belonging 17 species. The creek walls samples contained 200106 organisms (12.48%) belonging to 11 species. The central channel and the mud flats samples contained 347907 (12 species; 21.69%) and 1055980 (11 species; 65.83%) respectively. Enchytraedae (37.43%) was the dominant species in Dartford Creek in summer. This was followed by other oligochaete species namely: *Tubifex tubifex* (26.82%), *Amphicaeta sannio* (23.08%), *Limnodrilus claparedianus* (4.99%), *Heterochaeta costata* (3.68%) and *Limnodrilus variegates* (3.12%). The most abundant non oligochaete species in summer was *Nereis diversicolor* (0.40%).

The total number of organisms collected from the Dartford Creek in winter was 877 belonging to 4 species. Of these 23 organisms (2.62% of winter total) belonged to only 1 species were collected from the creek wall, 463 (4 species; 52.79%) from the central channel and 391 belonging to 4 species (4.56%) from the mud flats. Dartford Creek contributed 7.54% of the total number of organisms from the 15 sites. *Nereis diversicolor* (63.85%) is the most abundant species in the Dartford Creek in winter.

The amphipod crustaceans *Corophium volutator* (20.52%), *Corophium arenarium* (10.49%) and *Gammarus zaddachi* (5.13%) were well represented in the winter samples.

An overview of the organisms found in the creeks system

A total of 18290998 organisms spread over 32 species. *Psammoryctides barbatus* and *Tubifex pseudogaster* occurred only in winter in Chelsea Creek. Mud dwelling organisms were the main inhabitants of the creeks. Oligochaete species contributed 99.54% of the total macroinvertebrate organisms in summer in the creeks and most of these organisms were sampled from the creek mudflats. The polychaete worm *Nereis diversicolor* was the second most abundant organism in the mid estuarine creeks. In the summer the creeks walls and or central channels contained *Corophium volutator*, *Corophium arenarium*, *Asellus aquaticus*, *Gammarus zaddachi*, *Cordylophora caspia*. *Assiminea grayana*, , *Anurida maritima* and oligochaete species. *Eriocheir sinensis* were found in the Chelsea and Deptford Creeks but not in the other downstream creeks. Chironomidae were universally present. Tipulidae were present in all the creek walls. The annelid species *Helobdella stagnalis* and *Glossiphonia complanata* were present in the upper estuarine creek of Chelsea. Throughout the creeks the most abundant species in summer were the oligochaete species Enchytraedae (25.55%), *Amphicaeta sannio* (21.54%), *Limnodrilus hoffmeisteri* (12.18%), *Branchiura sowerbyi* (5.38%), *Limnodrilus claparedianus* (4.60%), *Heterochaeta costata* (4.04%) and *Limnodrilus variegates* (1.52%) (see Table 3.8)

In winter oligochaete species accounted for 99.91% of the total winter organisms but they were all sampled from the Chelsea Creek. The amphipods *Corophium volutator* (0.034%) and *Gammarus zaddachi* (0.02%) were the second and third most abundant species respectively. *Corophium arenarium* and *Gammarus zaddachi* were present in all the creeks but *Corophium volutator* only occurred from downstream Deptford. Chelsea Creek surprisingly contained the only oligochaete species sampled from the creeks in winter namely *Branchiura sowerbyi*, Enchytraedae, *Limnodrilus claparedianus*, *Psammoryctides barbatus* and *Tubifex pseudogaster*. In winter, throughout the creeks the most abundant species were *Tubifex pseudogaster* (58.05%) *Limnodrilus claparedianus* (15.23%) and *Psammoryctides barbatus*, but occurring only in Chelsea Creek, were the dominant species in winter. In the mid estuarine creeks the crustacean species *Corophium volutator* (0.03%), *Gammarus zaddachi* (0.02%) and *Corophium arenarium* (0.01%) were the most abundant species (Table 3.9)

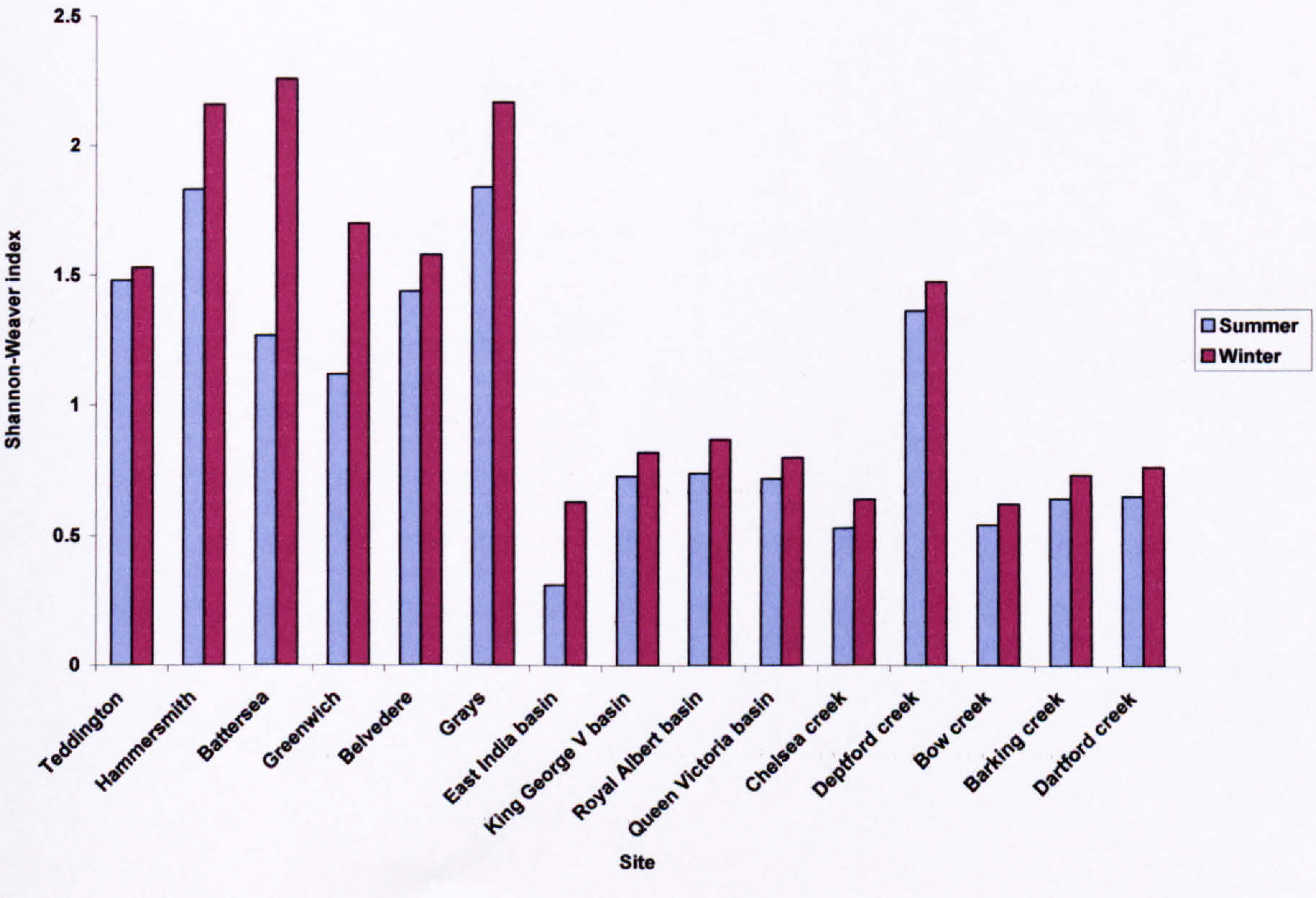
Species evenness (Shannon-Weaver index) – all sites

The Shannon-Weiner index is a relative measure of species richness and equitability. The index measures how evenly the total number of individuals in a sample is apportioned between each species (equitability). The results of the Shannon-Weaver index calculations for each site or locality along the Upper and Mid Thames Estuary and its associated creeks and docks are tabulated in Table 3.10 and plotted in Figure 3.3 to visually show their variations in season and site.

Table 3.10 summer and winter values of the Shannon-Weaver indices of species diversity

Site	summer	Winter
Teddington	1.48	1.53
Hammersmith	1.83	2.16
Battersea	1.27	2.26
Greenwich	1.12	1.70
Belvedere	1.44	1.58
Grays	1.84	2.17
East India basin	0.31	0.63
King George V basin	0.73	0.82
Royal Albert basin	0.74	0.87
Queen Victoria basin	0.72	0.80
Chelsea creek	0.53	0.64
Deptford creek	1.36	1.47
Bow creek	0.54	0.62
Barking creek	0.64	0.73
Dartford creek	0.65	0.76

Figure 3.3 Summer and winter Shannon-Weaver index values



Strong seasonal variations in the Shannon-Weaver indices were evident with marked drops in summer values below the winter values. This is because of the pronounced loss of individuals of the dominant species in winter increasing the equitability of species. The Shannon-Weaver indices of species diversity at the creeks were lower than those of main river sites because of the high dominances by Polychaete and oligochaete worms in these sites. Despite seasonal variations observed (Table 3.10 and Figure 3.3), species evenness of macroinvertebrate organisms tended to reach the highest values at the main river. Species evenness remained high in the middle reaches of Battersea, Greenwich and Belvedere.

Similarity

For the spatial analysis of species distribution, it was assumed that data for summer and winter should correspond to distinct ecological conditions, and were therefore analysed separately. Summer and winter matrices of species versus sites were analysed using Simple Correspondence Analysis (SCA), considering data from each site. Figure 3.4 is the factorial map of the sites sampled for benthic macroinvertebrate in the summer of 2002. Figure 3.6 is the corresponding summer factorial map of species x sites. Figure 3.5 represents the factorial map of the sites sampled in winter and Figure 3.7 is the corresponding winter factorial map of species x sites. The analysis of matrices of species x stations reveal clear differences between the macroinvertebrate communities of the upper and the middle reaches of the estuary.

Figure 3.4 Factorial map of the sites sampled for macroinvertebrate organisms in summer 2002

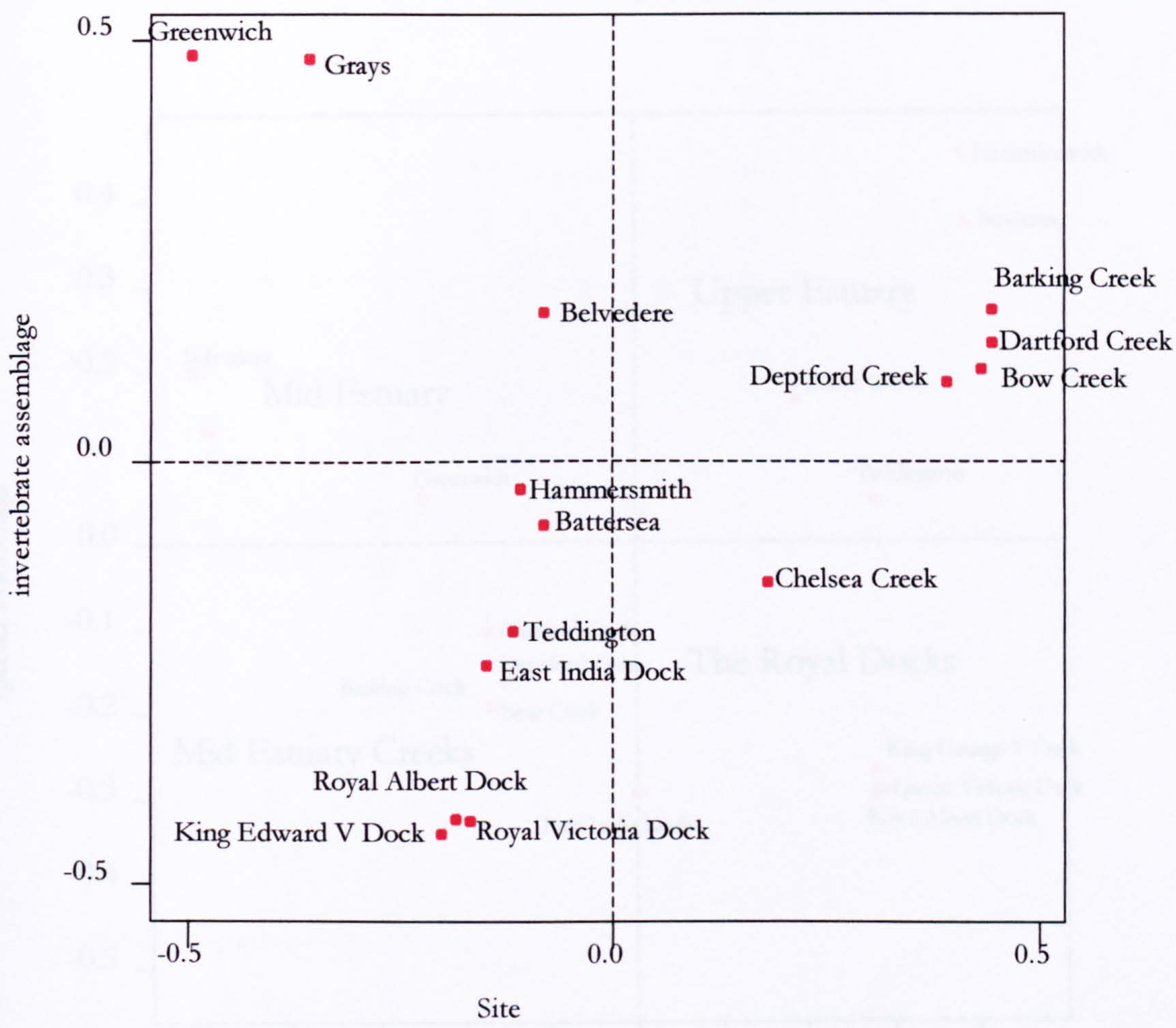


Figure 3.5 Factorial map of the sites sampled for macroinvertebrate organisms in winter 2002

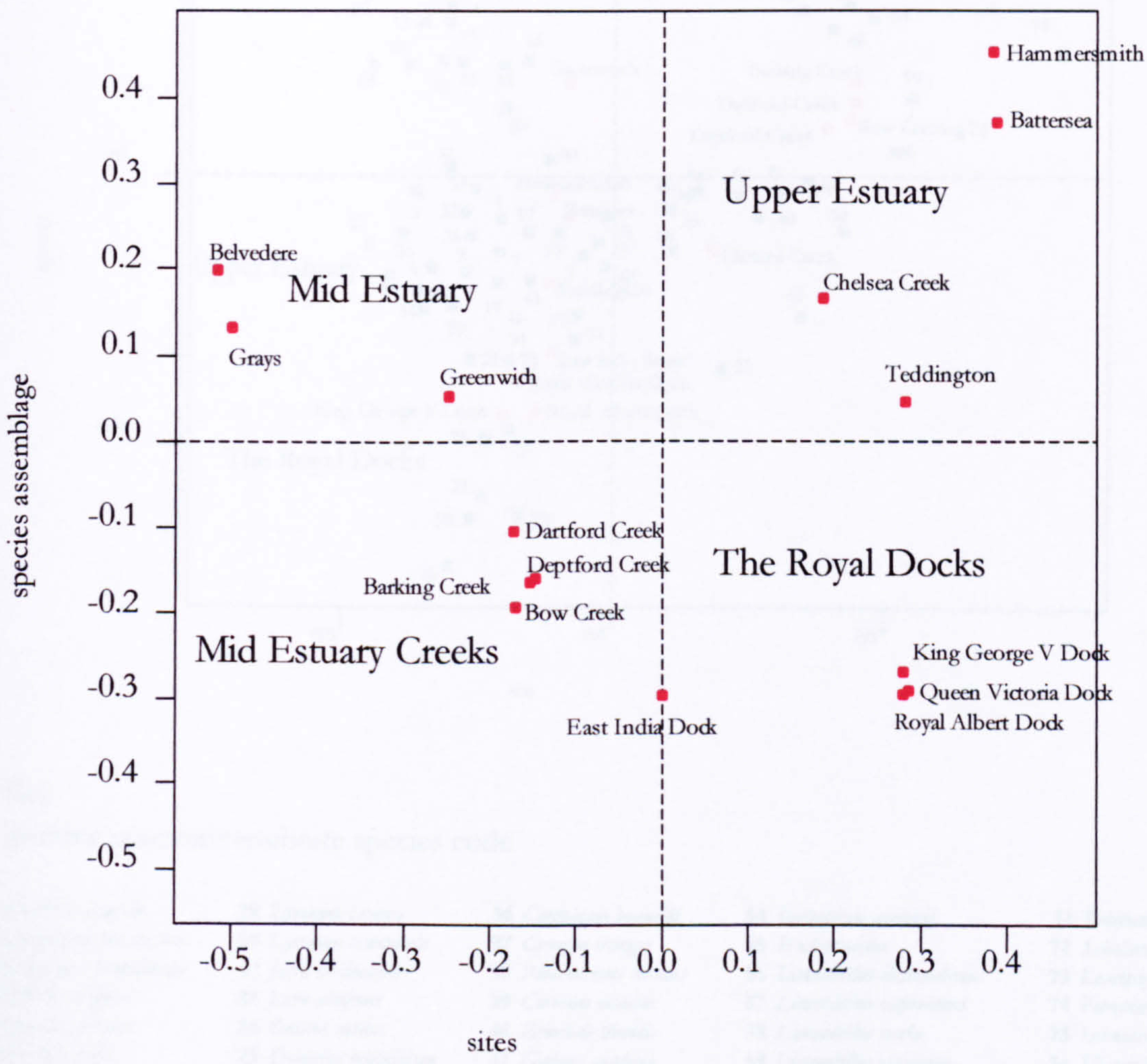
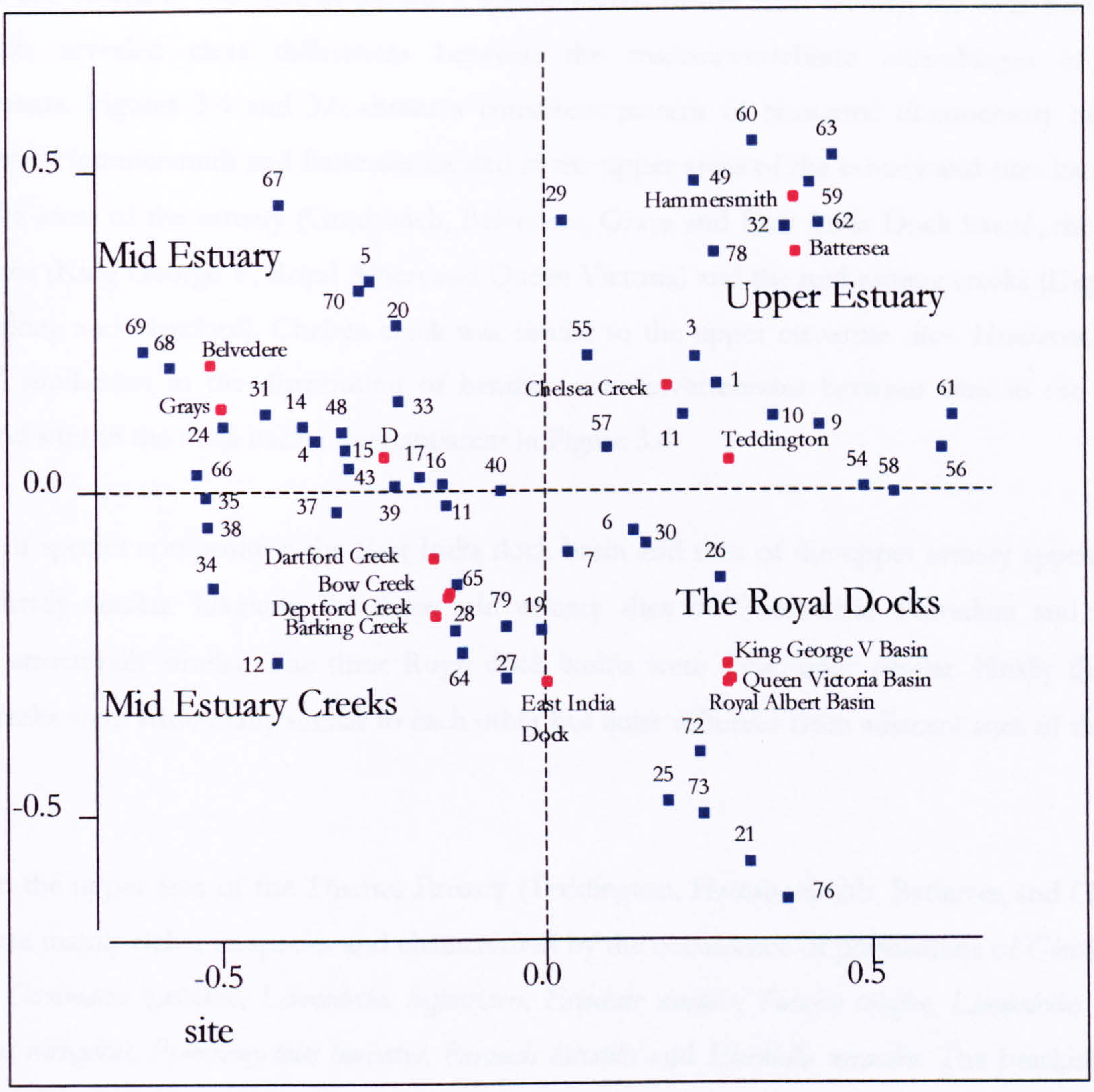


Figure 3.6 Factorial map of sites x species for summer 2002

- Site
- Benthic macroinvertebrate species code

1 *Helobdella stagnalis*
2 *Glossiphonia heteroclitta*
3 *Glossiphonis complanata*
4 *Hydrobia neglecta*
5 *Hygrobia jenkinsi*
6 Hirudinae sp
7 *Erpobdella testacea*
8 *Erpobdella octoculata*
9 *Dreissena polyporpha*
11 *Aurelia aurita*
12 *Nereis diversicolor*
13 *Nereis viren*
14 *Perenereis cultrifera*
15 *Nephtys hombergi*
16 *Scoloplos armiger*
17 *Mesopodosis slabberi*
18 *Theodosus fluviatilis*
19 *Lymnaea peregra*
20 *Lymnaea truncatula*
21 *Jaera nordmanni*
22 *Jaera albifrons*
24 *Oniscus asellus*
23 *Deroceras reticulatum*
25 *Sphaeroma hookeri*
26 *Asellus aquaticus*
27 *Balanus amphitrite*
28 *Balanus improvisus*
29 *Gamarua duebeni*
30 *Gammarus zaddachi*
31 *Gammarus salinus*
32 *Gammarus pulex*
33 *Corophium locusta*
34 *Corophium volutator*
35 *Corophium anenarium*
36 *Corophium bonnellii*
37 *Crangon crangon*
38 *Palaemonetes varians*
39 *Carcinus maenas*
40 *Eriocheir sinensis*
41 *Gyrinus marinus*
42 *Haliplus immaculatus*
43 *Hydrobia ulvae*
44 *Anotylus sculpturatus*
45 Chrysomelidae sp
46 Tipulidae sp
47 Psychodidae
48 Chironomidae
49 *Assiminaea grayana*
50 *Anurida maritima*
51 Acari sp
52 Nimatoda sp
54 *Branchiura sowerbyi*
55 *Enchytraeidae*
56 *Limnodrilus claparedianus*
57 *Limnodrilus hoffmeisteri*
58 *Limnodrilus cervix*
59 *Limnodrilus variegatus*
60 *Psammoryctides barbatus*
61 *Tubifex tubifex*
62 *Paranais littoris*
63 *Eiseniella tetraedra*
64 *Amphicaeta sannio*
65 *Thalassodrilus prostatus*
66 *Heterochaeta costata*
67 *Lumbriculus variegatus*
68 *Monopylepthorus rubroniveus*
69 *Potamothrix hammoniensis*
70 *Tubifex pseudogaster*
71 *Tubifecoides benedii*
72 *Sabelaria alveolata*
73 *Leucophytia bidentata*
74 *Petrobius brevistilis*
75 *Ischnura elegans*
76 *Victorella pavida*
77 *Symptrum sanguineum*
78 *Eiseniella tetraedra*
79 *Potamothrix hammoniensis*
80 *Sphaerium corneum*

Figure 3.7 Factorial map of sites x species for winter 2002



- Site
- Benthic macroinvertebrate species code

1 *Helobdella stagnalis*
2 *Glossiphonia heteroclitta*
3 *Glossiphonis complanata*
4 *Hydrobia neglecta*
5 *Hygrobia jenkinsi*
6 Hirudinae sp
7 *Erpobdella testacea*
8 *Erpobdella octoculata*
9 *Ddreissena polymorpha*
10 *Mytilus edulis*
11 *Aurelia aurita*
12 *Nereis diversicolor*
13 *Nereis viren*
14 *Perenereis cultrifera*
15 *Nephtys hombergi*
16 *Scoloplos armiger*
17 *Mesopodosis slabberi*
18 *Theodosus fluviatilis*
19 *Lymnaea peregra*
20 *Lymnaea truncatula*
21 *Jaera nordmanni*
24 *Oniscus asellus*
25 *Sphaeroma hookeri*
26 *Asellus aquaticus*
27 *Balanus amphitrite*
28 *Balanus improvisus*
29 *Gamarua duebeni*
30 *Gammarus zaddachi*
31 *Gammarus salinus*
32 *Gammarus pulex*
33 *Corophium lacusta*
34 *Corophium volutator*
35 *Corophium anenarium*
37 *Crangon crangon*
38 *Palaemonetes varians*
39 *Carcinus maenas*
40 *Eriocheir sinensis*
43 *Hydrobia ulvae*
48 Chironomidae
49 *Assiminaea grayana*
54 *Branchiura sowerbyi*
55 *Enchytraeidae*
56 *Limnodrilus claparedianus*
57 *Limnodrilus hoffmeisteri*
58 *Limnodrilus cervix*
59 *Limnodrilus variegatus*
60 *Psammoryctides barbatus*
61 *Tubifex tubifex*
62 *Paranais littoris*
63 *Eiseniella tetraedra*
64 *Amphicaeta sannio*
65 *Thalassodrilus prostatus*
66 *Heterochaeta costata*
67 *Lumbriculus variegatus*
68 *Monopylepthorus rubroniveus*
69 *Potamothrix hammoniensis*
70 *Tubifex pseudogaster*
72 *Sabelaria alveolata*
73 *Leucophytia bidentata*
76 *Victorella pavida*
78 *Eiseniella tetraedra*
79 *Potamothrix hammoniensis*
80 *Sphaerium corneum*

Summer situation

Based on the summer months macroinvertebrate data the 15 sites/ecological regions have been compared using Simple Correspondence Analysis (SCA). The total number of species sampled from the 15 sites in summer was 78. *Mytilus edulis* were found and *Aurelia aurita* were not sampled in summer. The results of the SCA of the site x species matrix of the main estuary, the dock basins and the creeks revealed clear differences between the macroinvertebrate assemblages of these environments. Figures 3.4 and 3.6 shows a consistent pattern of structural discontinuity between Teddington, Hammersmith and Battersea located in the upper areas of the estuary and sites located in the middle areas of the estuary (Greenwich, Belvedere, Grays and East India Dock basin), the Royal dock basins (King George V, Royal Albert and Queen Victoria) and the mid estuary creeks (Deptford, Bow, Barking and Dartford). Chelsea creek was similar to the upper estuarine sites. However, some structural similarities in the distribution of benthic macroinvertebrates between sites in the upper estuary and sites in the dock basins were apparent in Figure 3.6

In terms of species composition the East India dock basin and sites of the upper estuary appeared to be structurally similar. Likewise the three mid estuary sites of Greenwich, Belvedere and Grays appeared structurally similar. The three Royal dock basins were structurally similar. Finally the mid estuary creeks were structurally similar to each other but quite different from adjacent sites of the mid estuary.

Sites from the upper area of the Thames Estuary (Teddington, Hammersmith, Battersea and Chelsea Creek) were mainly richer in species and characterised by the occurrence of populations of *Glossiphonia heteroclita, Gammarus zaddachi, Limnodrilus hoffmeisteri, Eriocheir sinensis, Tubifex tubifex, Limnodrilus cervix, Limnodrilus variegatus, Psammoryctides barbatus, Paranais littoralis* and *Eiseniella tetraedra.* The brackish mid estuary sites were mainly characterised by the occurrence of *Hydrobia neglecta, Nereis diversicolor, Nereis viren, Perinereis cultrifera, Nephtys hombergi, Mesopodopsis slabberi, Lymnaea truncatula, Gammarus salinus, Psammoryctides barbatus, Corophium bonnellii, Eiseniella tetraedra, Gammarus duebeni, Lumbriculus variegates, Potamothrix hammoniensis, Monopylepthorus rubroniveus* and *Tubifex pseudogaster*.

Sites located in the Royal dock basins which represent impounded water systems/environments of depths in excess of 60 ft (Royal Docks Management Authority, 2004) with concrete walls and no riparian vegetation or foreshore (except for a narrow artificial beach located in the East side of the Queen Victoria dock basin for water sports) were characterised by the occurrence of high densities of the crustaceans *Jaera nordmanni*, Balanus sp, *Gammarus zaddachi, Crangon crangon, Palaemonetes varians, Branchiura sowerbyi, Sabellaria alveolata, Leucophytia bidentata, Victorella pavida* and *Symptrum sanguineum*

Sites located in the estuary creeks represent brackish or saline areas of their respective tributaries with three distinct habitats: thick mud banks, a central channel with shingle or rocky substrates which contains fresh water at low tide and the flood defence walls made up of wood or concrete at different stages of decay where they are present. These sites were characterised by the presence of large communities of oligochaetes worms in the mud flats, central channel and the submerged parts of the flood defence walls. The oligochaete species *Tubifex tubifex, Paranais littoris,* Enchytraedae, *Tubificoides benedii, Eiseniella tetraedra, Limnodrilus variegates, Amphicaeta sannio, Heterochaeta costata* and *Potamothrix hammoniensis* were widely present with varying densities depending on the part of the river the creek is located.

The winter situation

The total number of species sampled from the 15 sites in winter was 64. The species *Jaera albifrons, Deroceras reticulatum, Corophium bonnelli, Gyrinus marinus, Haliplus immaculatus, Anotylus sculpturatus,* Chrysomelidae sp, Tipulidae sp, Psychodidae sp, *Anurida maritime,* Acari sp, Nimatoda sp, *Aurelia aurita, Petrobius brevistylis, Ischnura elegans* and *Symptrum sanguineum* were generally absent in winter. Contrary to the *a priori* hypothesis that species composition of the upper and mid Thames Estuary tended to be 'homogenised' in winter due to higher input of freshwater from the upper Thames and the subsequent dilution of the lower estuary a more pronounced structural discontinuity was observed in the winter species composition of these environments. As in summer, the upper estuary site, mid estuary sites, mid estuary creeks and dock basins formed 4 different clusters (Figure 3.5 and 3.7). However, the East India dock basin no longer clustered with the upper estuarine group.

Figure 3.7 depicts the winter species distribution of sites in the Upper Thames Estuary and the upper estuarine creek site (Chelsea Creek), the Mid Estuary, sites in the Royal Dock basins and the mid estuary creeks. In winter sites in the upper estuary (Teddington, Hammersmith, Battersea and Chelsea Creek) were characterised by the presence of *Glossiphonia complanata, Helobdella stagnalis, Limnodrilus hoffmeisteri, Limnodrilus claparedianus, Limnodrilus cervix, Limnodrilus variegatus, Tubifex tubifex, Eiseniella tetraedra, Gammarus duebeni, Hirudinae sp., Gammarus pulex,* and *Gammarus zaddachi.* These are freshwater species. Sites in the mid estuary (Greenwich, Belvedere, Grays and East India Dock basin) were characterised by the abundance of *Crangon crangon, Carcinus maenas, Heterochaeta costata, Amphichaeta sannio, Hydrobia ulvae, Eriocheir sinensis, Nereis viren, Perinereis cultrifera, Balanus amphitrite, Balanus improvisus, Nephtys hombergi,* Sites in the Royal Dock basins were characterised by the abundance of rather few species *Sabellaria alveolata, Sphaeroma hookeri, Asellus aquaticus, Gammarus salinus, Jaera nordmanni,* and *Victorella pavida.* Sites in the estuarine creeks were characterised by the abundance of *Lymnaea peregra, Potamothrix hammoniensis, Thalassodrilus prostatus, Psammoryctides barbatus,, Palaemonetes varians, Corophium volutator* and *Corophium anenarium*

3.5 Discussion

A number of studies have compared the ability of the different estuarine zones of the River Thames to support varying densities of invertebrate communities. Most of these were longitudinal studies of the distribution of invertebrates along the salinity gradients and have become classic studies with some interesting recent updates, as follows: Huddart (1971a), Sedgwick and Arthur (1976), Andrews (1977), Andrews and Richards (1980), Andrews *et al* (1992), Atrill *et al* (1996), Leeming (1997) and Attrill (2002). None of these studies has concurrently targeted sites along the Thames and other associated water bodies such as creeks and dock basins. By not doing so the similarities and differences in assemblages between the reaches of the Thames Estuary and these water bodies has remained un-investigated until the current study.

Huddart (1971a) found shrimps to be the most abundant macroinvertebrate species occurring in the Thames Estuary from September to February-April, but during this period the numbers fluctuated considerably, and there was evidence that low numbers were associated with low oxygen concentrations. Laboratory experiments by Huddart (1971a) showed that reduced oxygen altered the swimming pattern of the shrimps, resulting in shrimps being carried away by the tidal current. In a later study in another British estuary, the Aber Estuary, Williams and Williams (1998) observed and concluded that many of the swept away freshwater invertebrates appear not to die upon passing tidal sections but resumed a benthic existence by virtue of varying degrees of salt tolerance. In Sedgwick and Arthur (1976), the effect of a strike of sewage works employees in 1970 on the populations of fish and shrimps in the Thames Estuary were described. In that study the chemical condition of the estuary, the effects of weather changes and the distribution of estuarine fauna were dealt with, and the changes observed resulting from the pollution were assessed by comparing data with faunal distributions from previous and subsequent years. In the current study, although physicochemical variables were not measured, on account of known salinity gradients and the assumption that oxygen saturation is no longer a serious issue for the reproduction and survival of animals in the waters of the Thames Estuary based on recent conclusions by Araujo *et al* (1998 and 1999) and Colclough *et al* (1998; 1999) and Colclough (1996 and 2001) seasonality accounts for the largest variation in the population of shrimps and other macroinvertebrate organisms in the Thames Estuary and its associated water bodies.

In a study carried out by Atrill *et al* (1996), benthic macroinvertebrates samples taken from 28 sites within the Thames Estuary between 1989 and 1992 and meiofauna samples taken for the first year, revealed 1 sub-tidal site which had over 200 invertebrate species from a sample area of 4.4 m^2. The most important groups at this site were Nematoda (77 species), Crustacea (46 species) and Polychaetes (40 species).

Reports on studies of macroinvertebrates of other estuaries are numerous and in many of these studies e.g., Remane and Schlieper (1971), Wolff (1973) Gainey and Greenberg (1977), Day *et al* (1989), Barnes (1994), Hauer and Lamberti (1996) and Atrill (1998), the macroinvertebrate community consists of several hundred species from numerous phyla; other examples include Allan (1975), Morse *et al* (1980), Benke *et al.* (1984), Ward and Stanford (1991) including arthropods (insects, mites, scuds, and crayfish), molluscs (snails, river limpets, mussels), and annelids (segmented worms), nematodes (roundworms), and platyhelminthes (flatworms). Most benthic species found in these environments are associated with the surfaces of the channel bottom (e.g., bedrock, cobble, finer sediments) or other stable surfaces (e.g., concrete walls, fallen trees, snags, roots, submerged or emergent aquatic vegetation and even carrion) rather than being routinely free-swimming. Therefore to obtain these organisms in samples strategies must be devised in order to access the microenvironments they inhabit. The current study has confirmed that certain invertebrate species tend to inhabit specific substrate types e.g. the worms belonging to the groups Oligochaeta and Polychaeta were abundant in the mud flats of the mid estuary and the creek banks and the Amphipod and Gammarid shrimps were more abundant in gravel and sandy substrates, although the distribution of their species was also related to the salinity gradients.

Hydrologic processes, food resources, nutrient dynamics, riparian vegetation, exposure, pollution, and many other factors are said to affect the diversity and densities of macroinvertebrates in estuaries and the general structure and function of the estuarine ecosystems (Hynes 1960), Cummins 1974, Huddart 1971, Allan 1995, Thorne and Williams 1997). A fundamental characteristic of these factors is that they change along the longitudinal gradient of the estuarine ecosystem (Vannote *et al.* 1980, Barnes 1994). These factors may be affected by various anthropogenic influences e.g., stream regulation (dredging, flood defences, damming, and as mentioned earlier pollution), Andrews (1977) and Ward and Stanford (1983). In the current study, macroinvertebrates composition has been observed to change between the dock basins, middle reaches, creeks and the upper estuary in response to change in the environment (mainly salinity gradients and substrate types).

The benthic fauna of the Thames Estuary contains a mixture of species originating from different other environments. There are relatively few species of benthic animals that are restricted to the estuarine zones. Freshwater benthic animals are frequently found in the oligohaline zones and many marine benthic animals occur in euryhaline zones, Huddart (1971a), Andrews (1974), Wolff (1973), Huddart (1971b), Sedgwick and Arthur (1976) Andrews 1977, Andrews and Richards (1980) and Atrill *et al* (1996).

A total of 80 taxa were collected in the summer and winter of 2002 from the upper and mid Thames Estuary and their associated Royal and East India Dock Basins and 5 estuarine creeks. The densities of species and dominant taxa are listed and described in Tables 3.1 and 3.2 for the main river and Tables 3.4 to 3.9 for other habitats

This current study has established that there are strong differences in macroinvertebrate assemblages between the estuarine zones as well as their associated water bodies, as expected with salinity and substrate differences. Zonal differences may also reflect differential response to and recovery from unmeasured disturbances. This study focuses on temporal patterns and physical habitat correlates with faunal distributions at each of the distinct sites and represents a preliminary attempt to connect these sites with habitat factors that may be most strongly affecting community composition of each site. The focus is on trends in total faunal abundance and the dominant species over time and space.

The upper estuary is characterized by relatively low salinity, summer riverside herb communities in the uppermost sites in combination with gravel substrates. The zone is characterised by relatively high species richness but low abundances. Forty-two species including 11 oligochaetes were identified from this zone. As expected from the low salinities, this zone is dominated by freshwater organisms, especially insect larvae (Chironomidae), certain amphipods belonging to the family (Gammaridae), Asellidae, the annelids, Hirudinae, Glossiphoniidae, Tubificidae, Naididae, Enchytraeidae, and the molluscs Assimineidae, Hydrobiidae and Mytilidae. Seasonality was strong, and there was a trend towards lower overall abundances in winter samples and higher abundances in the summer. However *Gammarus zaddachi* was more abundant in the winter months.

There was no clear pattern for long-term declines or increases in benthic abundances. However, the present study has limited ability to detect such trends because of only 1 year (2 seasons) of data. One clear pattern is high variability between seasons, emphasizing the need for long-term datasets in determining benthic community trends and cautioning against deriving too many conclusions from only 2 seasons set of data. To summarise patterns in the upper estuary, the most important characteristics are relatively high numbers of species but low abundances.

The mid estuary is characterised by brackish water and fine sediments in combination with hard substrates. The turbidity here is higher than that of the upstream zone. The mid estuary differs fundamentally from the upper estuary by having high macroinvertebrate abundances but low diversity of fauna. In this study a total of only 35 macroinvertebrate species including 17 oligochaete species were collected from this zone. As expected from the brackish water environment, this zone is dominated by a mixture of species of freshwater and marine origin, namely, oligochaetes, and Polychaetes worms. The polychaetes worms, which belong to two families (Nereidae and Nephtyidae) are abundant. The dominant oligochaete in the mid estuary belongs to the family Naididae followed by Enchytraeidae. There appears to be a positive coincidence between oligochaete and polychaete abundances. This relationship may reflect enhanced recruitment and food availability effects. This zone is also the turbidity maximum zone for the Thames Estuary, and turbidity patterns at this zone may reflect other relationships such substrate characteristics. A shift in the dominant Oligochaete species was evident. At sites along the upper estuary the tubificid *Tubifex tubifex* was most common being replaced at the middle and lower stations by the small Naididae *Limnodrilus hoffmeisteri*. The decapods Crangonidae and Palaemonidae were abundant especially in the Belvedere and Grays reaches. The post larvae of these crustaceans emerge in early April to late May to April, impacting on the availability of food sources of juvenile fish in the sub region to be discussed in later sections. To summarise patterns at Zone 2, the most important characteristics are relatively high faunal abundances but low numbers of species. The zone is occupied by species of freshwater and marine origins.

Sharing benthic macroinvertebrate assemblage similarities with both the upper and mid estuary are the benthic macroinvertebrate assemblages of the East India Dock Basin. This dock basin is characterised by high species richness but at the same time with a few species dominating the community. It is a mixed community consisting of most of the organisms present in the Royal dock basins and mid estuary in addition to a few species present in the basin but not collected anywhere else in the rest of the sites studied. This is expected since this basin underwent an extensive environmental enhancement following the addition of sediments and planting of a *Phragmites* reed bed and other estuarine marsh plants in the eastern margin of the basin. It is also tidal and has extensive estuarine mud flats deposited by the incoming tides. The calm water of the basin allows sediments to settle at high tide providing an environment for oligochaete and Polychaete worms. Its tidal property results in the ingress and egress of the main estuary fish and macroinvertebrate faunas. The families Sabellariidae, Lumbriculidae, Enchytraeidae, Tubificidae, Naididae, Nereidae, Hydrobiidae, Assimineidae, Balanidae, Asellidae, Janiridae, Sphaeromatidae, Crangonidae, Palaemonidae, and Chironomidae are present in this basin. This is also the only site where the larvae and post larvae of the insect families Coenagrionidae, Neanuridae and Machilidae are present. This is not surprising, because Barnes (1994) notes that insects of these families are mostly present in reedy lagoons; features which are the distinguishing features of the East India Dock Basin. Therefore the diversity and abundance of benthic macroinvertebrates is related to the presence of a highly heterogeneous environment, providing many habitat types for the occupation of a diverse estuarine macroinvertebrate assemblage.

A major impact of anthropogenic modification of habitats and resulting macroinvertebrate assemblages is well demonstrated in this study, the East India Dock Basin acting as a field laboratory.

This Dock had similar physical features to Royal Dock Basins until extensive environmental works were carried in and around it in 2000 by the Lea Valley Ecological Park Management Authority involving the addition of gravel and silt in the basin and the development of a foreshore with a *Phragmites* reed bed. This environmental works increased the complexity of the habitats in that dock basin and hence its capacity for colonisation by a diverse invertebrates communities. However, because of the high organic matter input by both the sediments, birds' droppings and the surrounding landscape the invertebrate community is dominated by oligochaete worms. Because of tidal water inundation regular flushing of excess nutrients occurs probably preventing the build up of toxic organic and mineral matter.

Although the numerical index of species richness (Shannon-Weaver Index) of the East India Dock basin was low (0.31) in summer compared to other sites, it had the highest species count amongst the dock basins. The structural modification of the East India dock and the construction of reed beds provided a much more natural habitat than the solid concrete structure of the Royal Docks. This has led to the colonisation of the area of a more diverse species. Evidence gathered by Hughes (1985) suggests that the most noticeable anthropogenic impacts to river biota usually results from changes in the basic structure and function of the river ecosystem.

The Royal Docks sites are characterised by low species richness and faunal abundances. They are dominated by species typical of hard marine substrates, low habitat heterogeneity and isolated brackish water environments. Oligochaetes are dominant by numbers but the noticeable benthic community is mostly crustaceans belonging to the families Sphaeromatidae, Janiridae, Gammaridae, Palaemonidae and Crangonidae and the tube dwelling annelid Sabellariidae. The community is typical of brackish water fauna consisting of both marine and freshwater species, with the marine fauna tending to dominate.

The Royal Dock basins were rich in crustacean species of marine or brackish water origin: *Sabellaria alveolata*, *Victorella pavida*, *Sphaeroma hookeri*, *Jaera nordmanni*, and *Jaera albifrons*. Lastly the analysis clearly reveals that the Royal Dock Basins have similar characteristic species assemblages to each other owing to their unique physical nature. However, because they are saline environments they also have species composition related to the main estuary. The dock basins generally lack diversity in physical habitats and their greater depths encourage the proliferation of epibenthic organisms and sessile organisms on the submerged walls. In these basins both solid and dissolved particulate organic matter is much reduced will also imply consequences for organisms that depend on detritus for food. Because of the need for the water to comply with statutory standards for contact water sports, anthropogenic organic inputs are extremely low – reinforced by by-laws. Unlike the main River Thames and the East India

Dock Basin there is no riverine detritus input due to efficient drainages surrounding dock basins to prevent runoff or combined sewage water from the surrounding area from entering the basins system.

It is tempting to assert that the communities of the Royal Dock basins are separated by clear, sharp boundaries, where group of species of the docks lie adjacent to those of the mid estuary but do not intergrade with them. Such an assumption will be an ecological unreality. The concrete walls of the Royal Dock Basins might appear to be a sharp physical boundary but its ecological unreality is emphasised by the movement of boats between the basins and the main river requiring the opening of the locks and the subsequent influx of water. Occasionally the locks are opened to allow water from the main river into the docks to maintain the water levels, plus the fact that the water in the basin originate from the main river. In the estuary, quite sharp boundaries occur between the low and high salinity zones where freshwater and salt water have greater influences. However, even in such existing situations, seawater and freshwater are mixed across the boundaries, which become increasingly blurred on a daily and seasonal basis (Kinniburgh, 1998). The safest statement that this study intends to make about community boundaries is probably that they do not strictly exist, but that some communities are much more sharply defined and the others are less sharply defined, e.g. comparing Battersea, the transition zone of the upper and the mid Thames estuary with Hammersmith 5.5 km upstream of Battersea to Grays which is within the transition zone between the mid and outer estuary.

In the estuarine creeks systems Oligochaetes were always numerically abundant. However, within this family the dominant species were not always the same. Significant associations between certain substrate characteristics and species abundances of specific faunal groups were observed. However, most of these associations appear to reflect concordant seasonality in faunal abundances and probably water chemistry rather than indicating any specific problem area.

The similarity between the invertebrate fauna of the four lower estuarine creeks appears very clear; these systems have very similar physical features characterised by mud deposits, gravel and stony central channels at low water, flood defence walls and are geographically close i.e. located in the brackish water zone of the estuary. They exhibit a great proportion of oligochaetes and polychaetes but other estuarine groups are also well represented. Opposite to this group of four creeks is the situation of the Chelsea creek, whose fauna are mainly of upstream origin. However, there are intra-site variations in species assemblages, e.g. the central channels of the creeks and mud banks exhibit differences in their fauna composition; the fauna of the creeks' central channels were related to the biogeographic origin of their freshwater species assemblages (macroinvertebrates of upstream faunal assemblages) brought downstream by invertebrate drift Waters (1972), Muller (1974), Kovalek (1979) Britain and Eikeland (1987).

A summary of the additional findings for the benthic macroinvertebrate assemblages in the upper and mid estuary and the associated water systems investigated is outlined below:

- The upper and mid estuary sites exhibit fundamentally different macroinvertebrates community structures. The upper estuary sites are characterised by high numbers of species, but low abundances. In contrast, the middle estuary sites including their associated creeks are characterised by fewer numbers of species, high abundances, and strong seasonality.
- The relationship between the macroinvertebrates assemblage of the upper and middle Thames Estuary are: the upper Thames estuary is characterised by richness in species of the freshwater members. Sites of the Mid Thames Estuary are intermediate between freshwater and marine faunas; its fauna include freshwater and marine assemblages.
- Although the mid Thames Estuary contains relatively few benthic species, the total abundance of organisms in a unit area of the estuarine bottom is very high, exceeding the average density in the upper estuary. This partially supports the commonly cited rule of estuaries: that the variety of organisms (the species richness) of the benthic community typically declines as one progresses from marine waters upstream into lower salinities (Remane and Schlieper 1971, Wolff 1973) although some recent researchers challenge that this rule has not been demonstrated adequately e.g., Abele and Walters (1979) and recently Attrill (2002). The rule was stated on the assumption that salinity always declines upstream, but this is not the case in "*reverse estuaries*" where freshwater input is not significant at certain times of the year that salinity actually increases upstream the estuary e.g., the Senegambia Estuary in West Africa, Baran (2000). This model is yet to be tested in these environments. In 1934 Remane described a model to explain the changes in the number of species along a full salinity gradient within the Baltic. Despite fundamental differences in tidal regimes, the Baltic model has been applied directly to estuaries, becoming subsequently the textbook model for estuarine diversity trends. However, Atrill (2002) tested this linear model for diversity trends in the Thames Estuary. Despite its ubiquity, the Remane model was criticised as having many inconsistent features, making it unsuitable as a quantitative tool for comparing diversity trends between estuaries, including poor definition of x-axis (salinity) and y-axis (number of species) and variation in sample location (sub-tidal/intertidal) that can greatly influence the resulting diversity relationship. Consequently, diversity trends within and between estuaries remain to be tested robustly. The model was tested by Attrill (2002) on an extensive sub-tidal dataset from the Thames Estuary (salinity 0-35). A significant negative linear relationship between salinity range and α-diversity was reported for annual seasonal data sets. In the current study similarity in macroinvertebrate assemblage characteristics similar to Remane's model was observed i.e. increasing densities and decreasing diversity with increasing salinities.

To take the subjectivity out of macroinvertebrate community descriptions, statistical techniques can be employed. Simple Correspondence Analysis (SCA) allows the data from macroinvertebrate community studies to sort themselves, eliminating the need to put in any preconceived ideas about which of the 80 species identified tend to be associated with each other or which habitat types associate most strongly with the species distribution. SCA is a mathematical treatment which allows communities to be organised on a graph so that those that are most similar in both species composition and relative abundance will appear closest together, while communities which differ greatly in the relative importance of a similar set of species, or which possess quite different species, appear far apart i.e. the upper estuary, mid estuary, creeks, and docks form discrete clusters (Figures 3.4 to 3.7). It is clear from Figure 3.4 and 3.5 that the Royal Dock basins are 'far away' from sites along the middle estuary sites in terms of ecological similarities (but not in terms of physical distance). The reason for this distance is probably because of the presence in the Royal Dock basins species of mostly marine origin and the general lack of species of freshwater origin. Figures 3.6 and 3.7 are more comprehensive, locating species in their habitats. The axes of the graph are derived mathematically solely from the species compositions of the various stands; they represent dimensions that effectively summarise the different community patterns.

The interpretation of the patterns in the SCA graph in terms of environmental variables is a second step, in which the scatter of points in the ordination is examined to see if the axes correspond to ecologically meaningful gradients. Obviously the success of the procedure depends on whether the appropriate sets of environmental variables are sampled. This is a major hurdle in the procedure - this study did not measure physicochemical variables; instead assumptions of salinity gradients based on 'local knowledge' obtained from previous sources such as Kinniburgh (1998), Araujo *et al.* (1998 and 1999) and Williams *et al,* (2000). The current study would have benefited from physico-chemical datasets by expanding the usefulness of SCA in the exploration of the range of factors that affects species distribution. In estuarine ecology the study of environmental factors namely dissolved oxygen, pH, salinity, suspended particles; etc is useful to demonstrate their impact on the fauna that interact with them. In the current study, the result of ordination study on the invertebrate communities existing in 15 locations along the upper and mid Thames Estuary, the Royal and East India Dock Basins and the estuarine creeks are graphically represented in Figures 3.6 and 3.7 for summer and winter. Clear relationships were revealed between habitat types and the position of the communities along the *x*-axis and between other habitats gradients (salinity gradients) along the *y*-axis. Once again, macroinvertebrates communities with predictable compositions occurred under specific sets of environmental conditions. If we know the salinity range and the substrate characteristics of a new location in the area the ordination could be used to predict the invertebrate fauna and if the fauna is only known the salinity range and the substrate characteristics can be predicted. This interrelationship can serve the purpose to provide biodiversity managers with a strong ecological knowledge about the estuary's macroinvertebrates fauna in order to enable them to make very viable and sustainable decisions in the management of the estuarine environment of the Thames Estuary and its associated habitats.

A multi-habitat approach was the approach that targeted shingle substrates in the upper Thames Estuary, mud flats in the mid Thames Estuary and creeks and vertical concrete flood defence walls in the dock basins. This approach introduced inter-site variability due in part to the different methods used to sample organisms in these habitats, and in part due to the differing proportions of habitats sampled. Consequently, between-site comparisons required detailed descriptions and recording of the proportion of habitats sampled to assist the interpretation of results.

The methods and sampling design used to collect the macroinvertebrates of the Thames Estuary have advantages but also some drawbacks. The rapid bio-assessment protocols in the UK (Dines and Murray-Bligh, 2000) primarily seek quick, cost-effective assessments of site ecological condition. Hand picking methods and the semi-quantitative kick net methodology appear to work well for macroinvertebrates (Barbour & Gerritsen 1996,). In this study the problems encountered with the hand picking method were: it was impossible to do hand picking at high or in turbid water; it had to be carried out at low tide. Secondly there was always a danger of picking terrestrial organisms that wandered about along the foreshore at low water. This increased the time needed to sort the organisms as occasional land based ones had to be separated and removed. Thirdly, it was very difficult to see organisms buried beneath sand, mud etc especially organisms that have camouflage and mimic the appearance of their surroundings. Sand hoppers (amphipod shrimps) for example were difficult to see in the sands and gravel mixture substrates of the upper estuary. Hand picking by area reduced the likelihood of variation in data due to the differences in the enthusiasm of the field staff employed and was consistent with protocols of Dines and Murray-Bligh (2000).

The main advantage of using kick nets in this study was their ease of use. They were easy to deploy and operate. The Environment Agency staffs that assisted in the sampling of the upper estuary had been using the kick net since 1990 to sample fish fry and benthic macroinvertebrates in their routine surveys, and were familiar with the process. Additionally the kick net was very economical, and can be used for many years before any need for replacement. They can be cleaned easily after use to prevent inter-site samples contamination. Another advantage was kick nets provided a point-in-time sample.

However, several problems were encountered whilst using the kick net. There were depth limitations with the kick net. The top of the net was approximately 1.5m high and could not be used in depths exceeding the top of the net. Thus most samples were taken along the shore. There has been other criticism of the bias [e.g. small sample size, consistent unit effort, negative contagion and the need for meaningful numbers per unit area] associated with this method (Courtemanch, 1996). Barbour and Stribbling (1991) recommend the use of subsamples and the use of appropriate subsample strategy for fixed-count procedures. The kick net technique used in this study appeared appropriate for determining presence of macroinvertebrate taxa, but it was inappropriate for calculating an estuarine condition index. The debate on these issues undoubtedly will continue for some time.

The Core sampler was extremely effective and was adapted to be small and light weight. The sampler used in this study was made from PVC pipe and metal edges added to cut roots and crusted soil. The technique of optimising sample size for core samples should satisfy Courtemanch's "small sample size" objection, but Barbour and Stribbling (1996) and Barbour *et al* (1999) would argue that an extensive inventory of this type would require inordinately large numbers of identifications and time. This was the experience as Core sampling was very time consuming and turned out to be more expensive to carry out than hand picking and kick sampling, even though the initial costs of obtaining the cores was very inexpensive.

Wall scraping was very cost effective and efficient but presented particular problems. During scraping some benthic macroinvertebrates were damaged and some of the substrate did not detach from the wall very well, and some invertebrates buried themselves deep into the crevices of the wooden and concrete walls. However, sampling was carried out when the substrates were wet and water logged to overcome some of these difficulties. A 10 x10 cm^2 area was always demarcated for scraping. Scraping by area was the best way feasible to standardise the sampling methods.

By convention, the term macroinvertebrates refers to invertebrates retained by a 0.5 mm net or sieve. Whereas a smaller mesh size may be required for detailed studies of life history, secondary production, or recolonisation; Winterbourn (1985) concluded that 0.5 mm mesh was sufficient for most sampling purposes. A 0.5 mm mesh net was used in all sampling in this study. 0.5 mm mesh collected much less fine sediment, was less prone to clogging, was easier to use in faster water, and collected samples that were quicker to process than samplers using finer 0.25mm mesh which was abandoned for the same problem. During kick sampling, much thought was concerned with standardisation of semi-quantitative sampling effort, Dines and Murray-Bligh (2000). For kick sampling, all kick sampling lasted for three minutes to ensure that samples from all sites where kick sampling was carried out were taken at equal time intervals. What were very difficult to standardise were the rigours applied in agitating substrates to dislodge organisms by different individuals. It was accepted that different individuals applied different physical effort, and would therefore dislodge organisms from the substrate into the net in varying quantities. With regards to core sampling the same sampler was used throughout and a 10 cm mark was used as the maximum depth the sampler was inserted into the substrate. For hand picking, consistency was achieved by the use of a pre-determined area approach.

The estimation of abundance for macroinvertebrate populations in this study involved two basic issues. First, the investigation was interested in areas that were sufficiently large that ground surveys cannot be conducted over the entire areas of interest. Faced with such situations, a sample of locations to survey were selected, and the selection was conducted in a manner that permitted inference about the entire upper and mid Thames Estuary, the impounded water systems (the dock basins) and the estuarine creeks, and thus about the locations not sampled. This is a standard problem in spatial sampling; statistical texts for example Cochran (1977) presents sampling designs and associated estimators to permit such inference. The second problem in benthic macroinvertebrates abundance estimation involves detectability or the idea that macroinvertebrate surveys methods seldom detect all the species present in any surveyed area or sample unit. Instead, macroinvertebrate survey methods involve collection of some sort of count statistic, and the investigator then must develop an estimator for the probability that a benthic invertebrate present in the area of interest appears in the count statistic. This probability also can be viewed as the expected proportion of the animals present that is actually detected.

Cost-effective sampling depends upon the collection of appropriately sized macroinvertebrate samples. Samples must be large enough to represent communities at the site adequately, but not so large that they are time consuming to process. Given the high spatial and temporal variability in macroinvertebrate communities in the different ecological regions of the Thames Estuary surveyed and variability introduced by different sampling personnel employed, it was not easy to give specific and unambiguous guidance on sample size. Three kick samples were used in each site per sampling day. Stark (1998) suggests that the representative macroinvertebrate sample from a hard bottomed stream can be obtained using a kick net (or similar) by sampling approximately 0.6 – 1.0 m^2 of streambed. Because of the need to estimate species densities and evenness, replicate samples were collected and sampling repeated on several occasions. For example, if macroinvertebrate taxon richness or densities seem low when collecting samples, collection of additional samples of the standard effort was preferred rather that simply increasing the sample size. Replicate samples were processed separately and were not composited. However, obtaining the optimum sample size for optimum species recovery required far more samples that were possible due to time and financial constrains. Richness metrics, are known to increase with sample size up to 18 m^2, indicating that the diversity indices that have been used as one of the methods for analysing the macroinvertebrates data obtained should be used with caution in soft-bottomed substrates such as the mud flat samples. These data also suggested that some minimally disturbed soft-bottomed sites may have very low invertebrate densities and that replicate samples may be needed to characterise macroinvertebrate community composition reliably. Core sampling was an expensive business and it was not possible to achieve such area coverage.

Samples were preserved for later identification in the laboratory. Preservation was carried out with the use of 4% formaldehyde (formalin), although this invariably was unpleasant or hazardous substance. Formalin (formalin) is a fixative that helped to maintain the colour and shape of macroinvertebrates. Full safety precautions (rubber gloves, adequate fume extraction) were used.

This investigation on the distribution and abundance of macroinvertebrate organisms has been aimed at describing, and ultimately trying to understand the pattern of distribution of benthic macroinvertebrates assemblages i.e. the variation in their abundances and richness in the Thames Estuary and its associated habitats in winter and summer. This study has identified areas of the Estuary that support particular populations of invertebrates as potential food supplies for juvenile fish. It has shown which potential food items can be obtained in winter and summer in sufficient abundance to support the different feeding requirement of fish. This study on macroinvertebrate distribution and abundance provides valuable information for the detailed studies on the diet of fish species that inhabit the estuary which was also investigated concurrently. A comparison of the fauna in the different habitats has provided an insight into the relative importance of the main river, creeks, tributaries and docks in supporting good populations of macroinvertebrates for foraging fish species.

The analysis of benthic macroinvertebrate assemblages of the upper and mid Thames Estuary the dock basins, the creeks and a tributary through winter and summer showed that biologically these water systems constitute different subsystems. This structural discontinuity was quite obvious between the Royal docks and the upper estuarine creek (Chelsea creek). On one hand, infaunal species such as oligochaetes and polychaetes were abundant in the mid estuary, East India dock basin and the creeks. On the other hand a clear dominance of epifaunal species was evident in the Royal docks and reaches of the upper estuary. Therefore it appeared that the extreme changes in community structures and macroinvertebrate assemblages amongst the Thames estuary and its associated water courses were also a function of habitat complexity in addition to salinity gradients.

The limitation of the macroinvertebrate studies

1. In this study sampling was restricted to sites that were accessible by foot due to the general difficulties of identifying suitable foreshores. Previous studies had sampled or obtained macroinvertebrate data more sites and extended their surveys to the outer estuary e.g., Andrews *et al* (1992), Atrill (1998) and Atrill (2002). Previous studies have shown that many sites support substantially higher macroinvertebrates diversities and densities. Higher densities of copepod crustaceans, polychaete and oligochaete worms in sites along the mid estuary have been reported Andrews *et al* (1992), Atrill *et al* (1996), Leeming (1997), Atrill (1998) and Atrill (2002). It is possible that macroinvertebrate diversity may have been higher if more sites were sampled. Furthermore it is acknowledged that macroinvertebrate taxon richness in disturbed areas and lower habitat diversity will be lower. Sites in Battersea and Hammersmith fit these descriptions so it was not surprising that such sites exhibited low macroinvertebrates densities. Another limitation was the lack of accessibility in many creeks and docks. The majority of potential sites in the creeks were not sampled for this reason.
2. This benthic macroinvertebrate study was conducted over a relatively short period of time (6 months) over two seasons only (July, August and September in summer and December, January and March in Winter), and did not account for spring and autumn differences in macroinvertebrate diversity.
3. Adequate keys to describe many estuarine species are currently few, so for some organisms it was only feasible to carry out identification to the family level. Although all organisms present would optimally be identified to the species level, measurement of species richness tends to be inexact because of the lack of species-level identification keys for the immature stages (the stages most commonly encountered in seasonal studies) of many groups of aquatic invertebrates In the UK, there is limited knowledge on the taxonomy, life histories and ecological requirements of estuarine macroinvertebrates.
4. All commonly used sampling techniques are very superficial, in that only the top few centimetres of the substratum are sampled. Some animals burrow deep within the substratum and only a proportion of these are recovered by commonly used sampling techniques such as kick and hand picking sampling. In addition, some studies indicate that the kick-sampling method can prove inadequate for highly mobile taxa that can flee from the sampling point.
5. A Shannon-Weaver index analysis is purely a quantitative technique requiring strictly quantitative sampling methods, and it must be noted that species density can significantly affect the outcome of the analysis. According to Abele and Walters (1979), a further level of sophistication is to estimate the degree of probability with which sites are similar or different. This is necessary because most samples do not include all the species present in the habitat.

6. Habitat productivity was measured using species numerical abundance and not biomass which often gave the impression that oligochaete species were the major fauna of the estuary because of their numerical abundance obliterating the importance of other species such as crustaceans which were far less numerous but in terms of biomass were probably several times higher in mass at any point in space and time than the oligochaetes.

Chapter 4

THE COMPOSITION AND RELATIVE ABUNDANCE OF FISH SPECIES IN THE UPPER AND MIDDLE THAMES ESTUARY AND ITS ASSOCIATED TRIBUTARIES AND DOCK BASINS

4.1 Abstract

A one-year monthly sampling program was carried out in the upper and middle Thames Estuary, the East India and Victoria Dock Basins using a 4mm knotless seine net. Additional data was acquired for the zones of Dartford Creek (River Cray and the Darent), a tributary of the Thames Estuary from the Environment Agency captured with a 10 mm between knots trawl net. Fish datasets were analysed using qualitative and quantitative statistical approaches. A total of 26 species were captured in all the sites; 10 species were common to all the sites. Twenty two species were recorded in the upper Estuary and 22 in the mid Estuary. Eighteen species were common to both the upper and middle Estuary. Eleven species were recorded in the Queen Victoria Dock Basin, 21 in the East India Dock Basin and 14 in the Dartford Creek. The most abundant family recorded through out the study was the Cyprinidae with 8 species occurring, mainly in the low salinity areas of the upper Estuary and the two arms of the Dartford Creek. In the Brackish waters of the mid Estuary, East India and Queen Victoria Dock Basins a far greater contribution came from marine species, although all families recorded in the tidal Thames except Cottidae were present in the mid Estuary and the East India Dock Basin.

4.2 Introduction

The aim of the fish study was to describe the composition and relative abundance of fish populations in the upper and middle zones of the Thames Estuary and associated water systems. The primary objective was to find out how the fish populations of the upper and mid Thames Estuary, Victoria and East India Dock Basins and Dartford Creek are related to each other. The results presented are based on a one year fish survey on the main river followed by the other surveys, which varied in their dates and intensity, using a fry seine net described in the following section. The sites investigated included 6 main river sites plus two dock basins and a creek as shown in Figure 2.2 (Chapter 2). Sampling in the main river was carried out from May 2000 to April 2001. Sampling in the East India Dock Basin was carried out from December 2001 to November 2002 and that in the Queen Victoria Dock Basin was carried out from April 2001 to March 2002. Belvedere and Grays sites were not sampled continuously. Sampling in the Belvedere site was discontinued after September 2000 because of net damage by rocks placed along the littoral and supralittoral to stabilise the river bank. Grays was substituted in October 2000 as an alternative site. The River Cray (Dartford Creek) was sampled in June, July, August and September

2001 by the Environment Agency. The variations in the sampling times were due to initial difficulties of obtaining sampling permission from the managing authorities of the Dock Basins.

4.3 Methodology

This section describes the various ways fish data was collected and analysed.

4.3.1 Existing Data

There is a substantial body of existing information available concerning fish distribution in the Thames Estuary. Collections of fish specimens and descriptions of their occurrence and distribution in the Thames Estuary had continued for more than 40 years (Wheeler 1969b) prior to his review. More recent detailed descriptions of fish species distributions have been compiled and summarized by the Environment Agency (Colclough, 1992 & 2001 and Colclough *et al* 1998, 1999 and 2000). Analysis of fish data allows fisheries personnel at the Environment Agency to compile species lists and develop maps of species distribution for education and public relations. The Environment Agency collected fish data for Dartford Creek, using a 10 mm between knots trawl net in June, July, August and September of 2001 at mid-tide level.

4.3.2 Sampling Permits

In the Thames Estuary, the sampling and collection of fish for scientific purposes is regulated through the Environment Agency who issues the relevant permits and typically require submitting a report summarising data-collection efforts. For the Royal Docks, authority is granted by the Royal Docks Management Authority (RODMA). For the East India Dock authority is granted by the Lea Valley Ecological Park Management Authority (LVPMA). Whereas obtaining a permit from the Environment Agency was straightforward, obtaining authority from RODMA and LVPMA was protracted and delayed the dock survey programme by a season.

4.3.3 Coordination of Sampling with the Environment Agency

Sampling was carried out to avoid sampling times clashing with other workers in the estuary. Efficient data collection requires coordination of sampling with other fish collecting agencies, including agency fisheries workers, and fisheries professionals employed by private organisations. These fish ecologists may have ongoing or planned sampling activities within the study area. Information on the location, timing, and objective(s) of their sampling activities was therefore obtained. Repeated sampling of an area by a number of different fish ecologists may seriously bias fish community data. Repeated collections of fish within a relatively short time period may reduce species diversity, thereby providing an erroneous representation of the fish community. Also, coordination of sampling with the Environment Agency also resulted in collaborative efforts that enhanced the characterisation of fish communities in the study areas.

4.3.4 Sampling plan

1. A monthly survey of fish populations at the main river sites was carried out over 1 year period from May 2000 to April 2001.
2. Monthly surveys of fish populations at the East India and Queen Victoria Dock Basins were carried out from December 2001 to November 2002 and April 2001 to March 2002 respectively.
3. Fish population data for Dartford Creek was provided by the Environment Agency from July 2001 to September 2001.

4.3.5 Equipment used

For the monthly fish survey at the main river sites and the sampling from Queen Victoria and East India Docks, shore based seine netting was adopted as the technique which would provide a standardised method of collecting fish from the foreshore habitats. A knotless micro-seine net 25m by 3m with a 4mm mesh was used for this survey. The top of the net had polystyrene floats to keep it at the surface and the bottom of the net was weighted with barrel leads evenly spaced to ensure that the net formed a vertical wall of netting reaching the river bed when it was deployed in the river. 30 m haul lines were attached to each end of the float and lead lines. The small mesh size permitted the capture of fish as small as 7mm in length and ensured that the young life stages of fish were caught soon after hatching. The choice of a relatively small 25m net was to enable the net to be handled by two operators and to be deployed in small foreshores. Knotless netting was selected as this type of mesh is much kinder to delicate fish species. However, the small mesh size was sometimes problematic due to the entrainment of large quantities of silt when sampling in soft sediment areas.

4.3.6 Seine netting

Fish sampling was undertaken at low water slack tide generally at mid month +/- 4 days, but avoiding the greater tidal amplitudes associated with spring tides. Sampling at low tide maximised wading access and avoided the problems of seine net setting in high water velocities. Standardisation of sampling time relative to the tidal cycle could also be expected to enhance data comparability both within and between sites. Slack water lasts approximately 45 minutes at the downstream sites, but becomes progressively shorter towards Teddington weir. Sampling sites for the current study were selected in order to complement and extend existing fish data. The sites themselves and the criteria for their selection are described and discussed in Chapter 2.

The net was set parallel to shore with two operators in the following manner: One person standing at the water line on the beach would hold one end of the haul line as the other person in the water backed away from and perpendicular to shore until shoulder deep. The person then turned parallel to shore and the net was released (set) as the person walked parallel to shore. Once all of the net was released, the haul line at the other end of the set net was returned to the shore. The haul lines were then pulled simultaneously, at an equal rate, and at a slightly oblique angle to form a wide arc of the net passing through the water and toward shore at a rate of approximately 4m/min. When the net was approximately 5 meters from shore, the individuals retrieving the net at each end would approach one another so the net opening closed to approximately 12 meters as the landward ends of the wings touched the beach. The wings were then drawn closer to within approximately 3 meters as the wings were drawn up onto the beach, making sure that the lead line remained on the bottom and forcing all fish down the centre. Once the lead line along the centre of the net reached the beach, the lead line and float lines were lifted simultaneously. Any fish remaining in the net were worked down into the centre of the net which was maintained in approximately 0.5m of water to retain a sufficient amount of water in the net for the catch. Debris and fish were removed from the catch, with the fish being transferred to buckets filled with water taken from the site. The set net was at an average distance of 15 m from the shore at Teddington, Hammersmith, Battersea and Grays sites and 13.7 m at the Greenwich and Belvedere. In winter, distances from the foreshore were all approximately equal at 13m at low tide reflecting seasonal differences in water depth. Therefore whilst depths of seining were standard, there were small temporal and spatial variations in distances from the shore. These were not considered to be significant.

As already stated, seine netting was undertaken at low tide slack water. Three net hauls were undertaken at each site on each sampling occasion and the catch transferred to holding tanks, so that fish processing could be deferred until after the third net haul. Due to tidal lag (approximately 3 hours between Grays and Teddington) it was possible to sample more than one site within the same tidal cycle. In contrast to the river, the docks are essentially still water systems and thus there were no constraints to sampling timing. The limitation here is the availability of suitable sampling sites due to the steep wall and deep water. However, an artificial beach at the Royal Victoria Dock provided an ideal sampling point. For the Environment Agency Dartford Creek surveys, sampling was undertaken at mid-tide as the Creek effectively empties at low tide.

4.3.7 Fish processing

All large fish >250 mm were identified, measured and released. In the early months of the programme, all other fish were retained and preserved in 4% formaldehyde for subsequent identification and measurements of fork length and ageing. In 2001, it was determined that a minimum of 250 individual fish of each species would be retained from each site for measurements (or all fish if individual species counts were less than 250) to improve statistical robustness. The remainder of the catch was transferred in buckets of site water to a processing station, which was set up on the beach prior to deploying the seine. At this station, fish were maintained in aerated buckets of site water until they could be counted. If necessary (i.e., during warm weather, or if processing took a long period of time), water was exchanged with fresh river water to maintain oxygen levels and cool water temperature. All individuals of all species were counted and large individuals (>250 mm) were measured prior to release. Smelt were usually processed first because they are typically more sensitive to handling and required more recovery time.

4.3.8 Fish data: Sorting, identification and enumeration of fish

In the laboratory, fish samples were emptied into plastic trays and rinsed thoroughly with tap water to remove formaldehyde. The fish were then sorted to species level with the aid of keys where necessary (Lithgoe and Lithgoe, 1971; Bagenal and Tesch, 1978; Wheeler, 1979; Maitland and Campbell, 1992; Barnes 1994). Each species was then counted and all individuals measured (fork length). The results for the monthly numbers for each of the sites are presented in Tables 4.3 to 4.14 for the main river and Tables 4.16., 4.18 and 4.19 for the Dartford Creek, Queen Victoria Dock and East India Dock respectively.

4.3.9 Aging and grouping of the fish into 0+ and 1+ year classes

Information about age composition is important in this study because a key component of the aims of the study is to investigate diet consumption patterns in 0+ and 1+ fish groups in order to gain information on the status of the estuary as a feeding ground. The results for the separation of fish into 0+ and 1+ groups are showed in Appendix 4 to Tables 1 – 12.

4.3.10 Use of the age length keys and length frequency distribution graphs

Age determination of individual fish is more difficult and time consuming than the recording of length measurements, but by using age-length keys, age distributions can be recorded without much difficulty from length distribution (Fridrikson, 1934). Knowledge of the age-length composition in the population or in a given subgroup of the population is required for constructing adequate age-length keys. Many fisheries organisations today use age-length keys that have been developed to age live fish in the field. The Environment Agency uses species age-length keys to age fish on the foreshore. This study adapted the age-length key as a first step for ageing fish samples into age classes and then the predicted age classes were confirmed by circuli readings. Specific methods for construction and evaluation of age-length keys are described by (Fridrikson, 1934; Schnute and Fournier, 1980; Hayes, 1993; Goodyear 1997). Because of individual variations in growth rates and the variation in mortality rates at different ages and sizes, the age and the length composition of a fish stock are constantly changing. With sufficient information about a fish stock, the change in the age-length composition can be modelled and theoretical age-length keys can be constructed, for specific time periods (Salthaug 2001). Age distribution can then be estimated from length distributions in samples taken at different times of the season. Salthaug (2001) describes a simple but useful modelling approach for constructing dynamic age-length keys and applied to data from Atlantic cod (*Gadus morhua*) stock in Barents Sea.

Figures 4.1 to 4.4 show length frequencies for sea bass, roach, smelt and common goby respectively and illustrate the clear separation of the 0+ cohort from the 1+.

Figure 4.1 Length frequency of sea bass caught by seine netting at Belvedere and Greenwich sites in July 2001

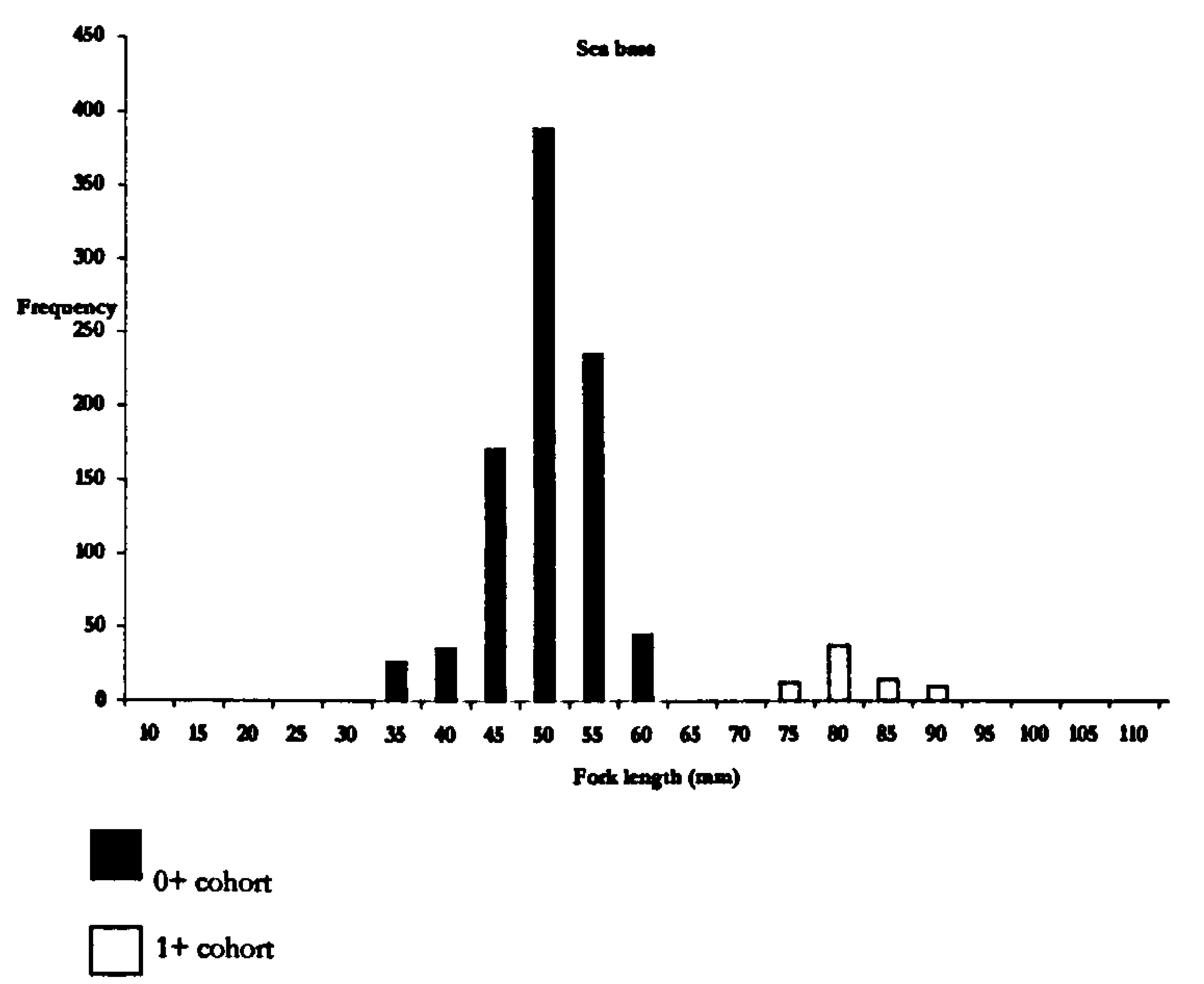


Figure 4.2 Length frequency of roach caught by seine netting in Teddington and Hammersmith in June 2001

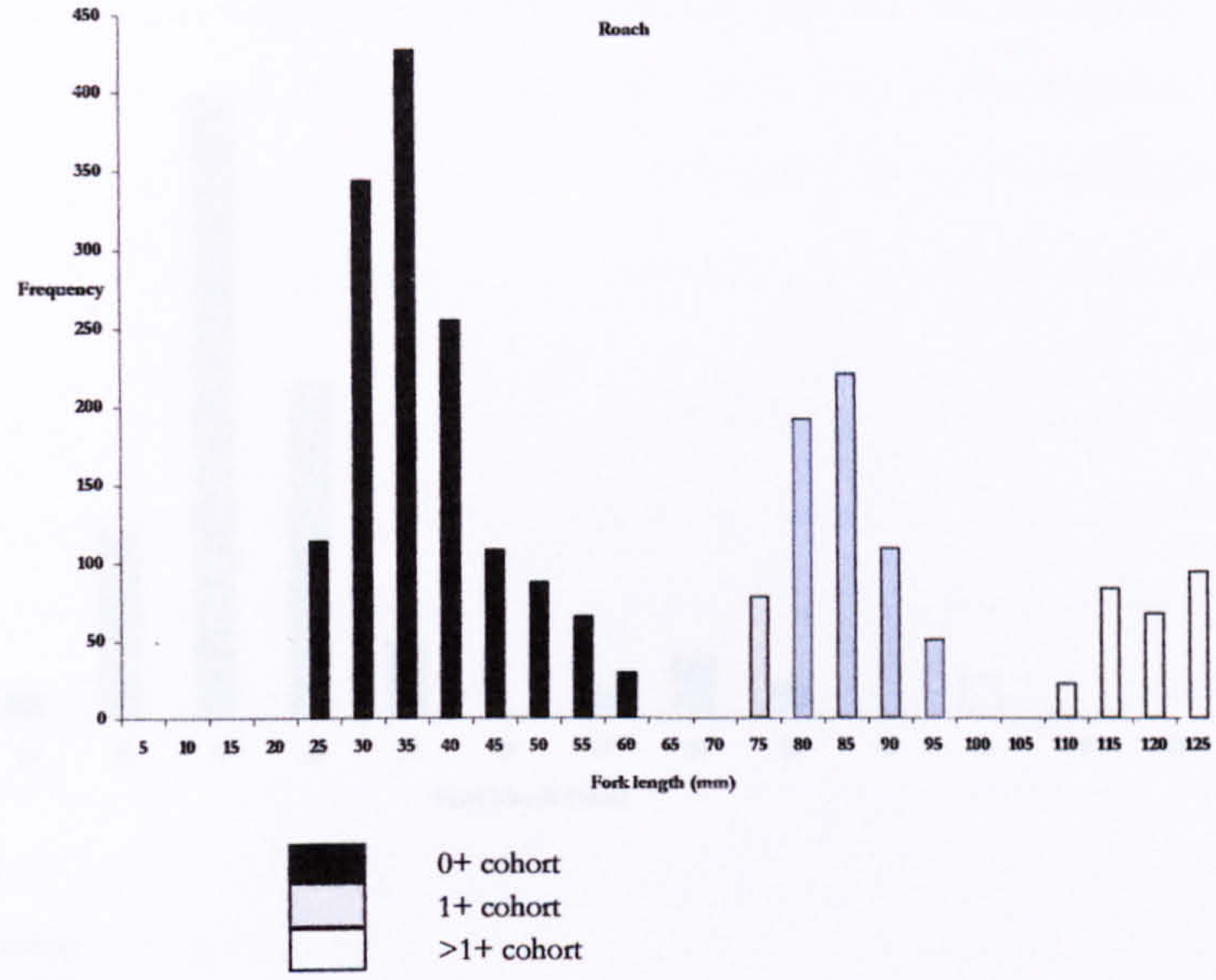


Figure 4.3 Length frequency of smelt caught by seine netting in Greenwich and Belvedere in June and July 2001

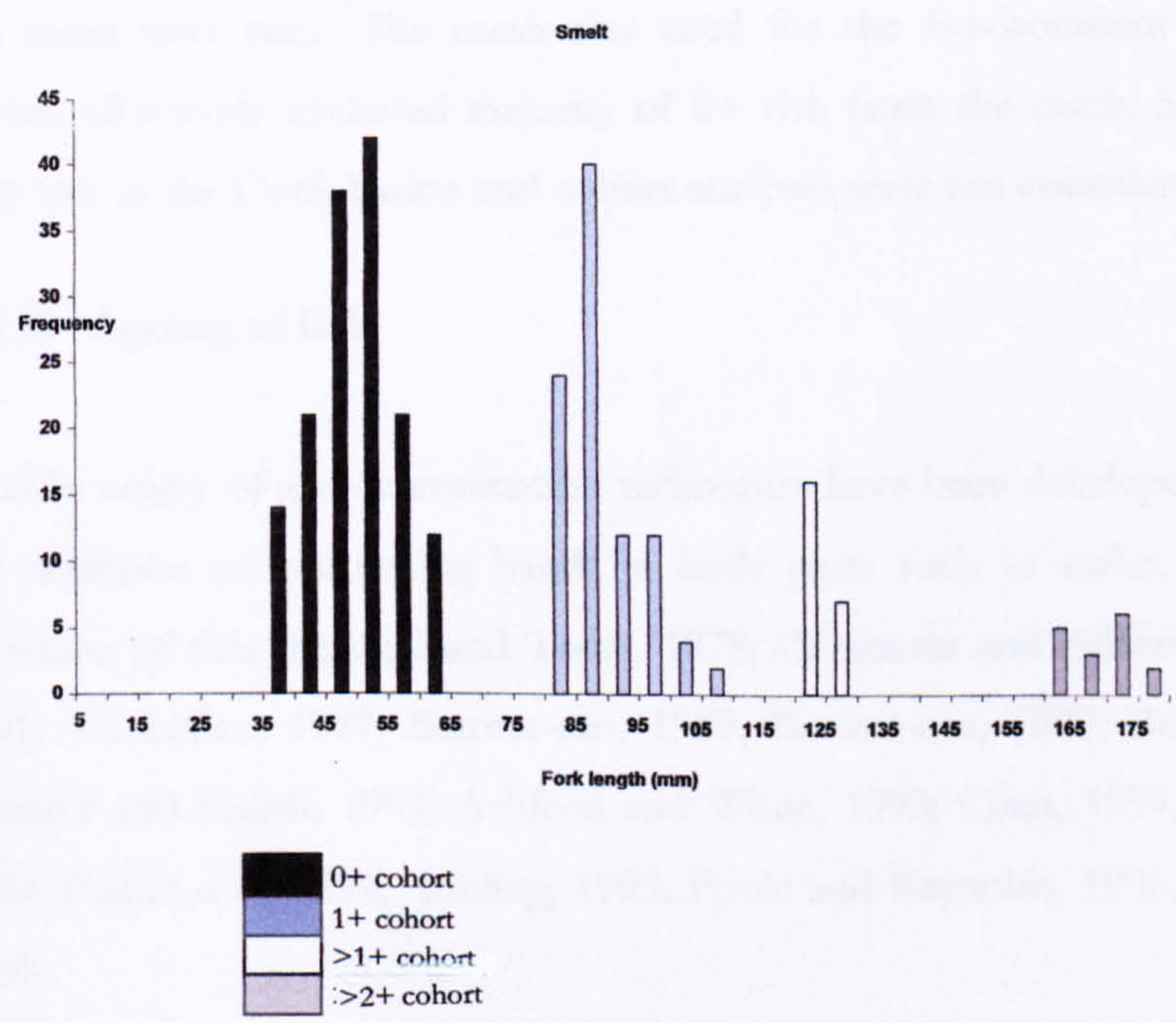
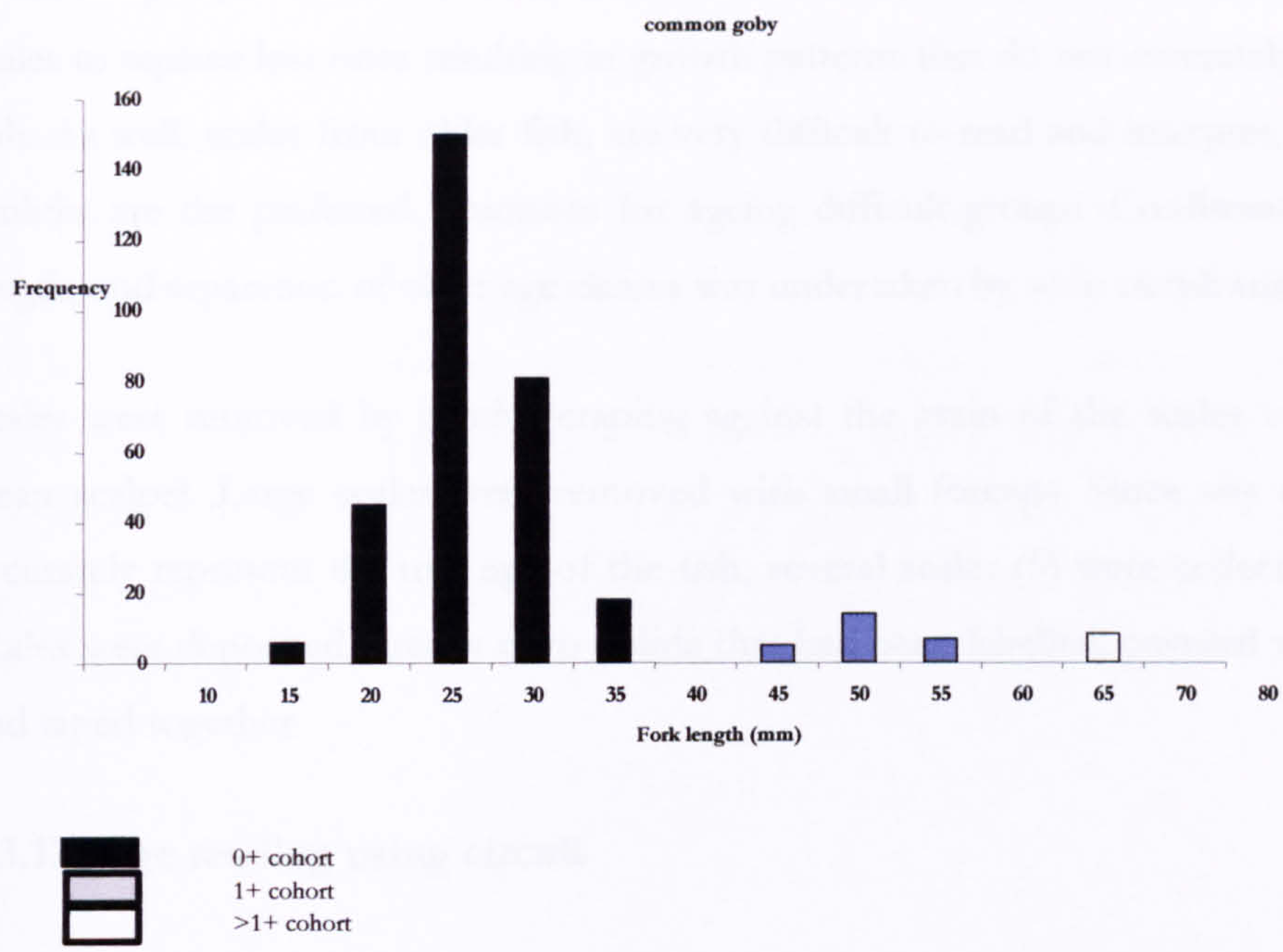


Figure: 4.4 Length frequency of common goby captured at Greenwich and Belvedere site in July 2001



Separation of 1+ ages based on length was less reliable due to potential length overlap of the cohorts. Age was therefore confirmed by circuli analysis as described below. The full data relating to age classes is given in Appendix 4. Age cohort analyses were only undertaken for the main river sites. The mesh size used for the Environment Agency's Dartford Creek survey effectively excluded majority of 0+ fish from the catch. Species diversity of 1+ was very low in the Dock basins and cohort analyses were not considered worthwhile.

4.3.11 Ageing of fish

A wide variety of age determination techniques have been developed for finfish which depend on the detection of contrasting bands in body parts such as scales, otoliths, fin rays, spines, and vertebrae of fish (Bagenal and Tesch, 1978; Chojnacki and Palczewski, 1981; Neilsen and Geen, 1981; MacLellan, 1987; Barrera-oro, 1989; Barrera-oro, 1990; Berg, 1990; Mackay *et al.*, 1990; Chisnall and Kalish, 1993; Ashford and White, 1993; Chen, 1994; Panfili and Ximenes, 1992 & 1994; Panfili *et al*, 1994; Jobling, 1995; Poole and Reynolds, 1996; Hamrin *et al*, 1999; Campana, 2001).

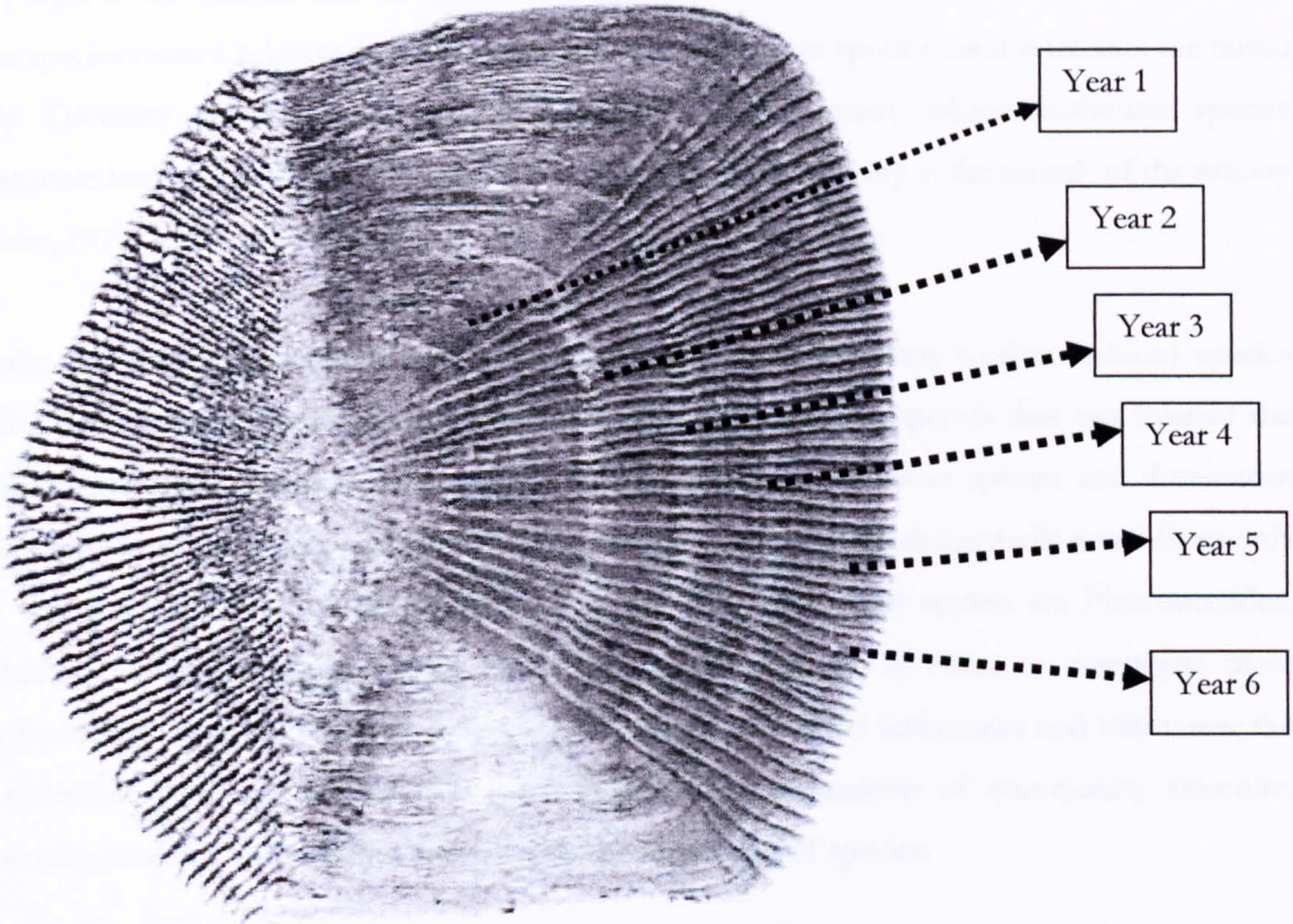
Traditionally, scales are one of the most common and convenient methods for determining the age of a fish. Scale removal is relatively quick and easy, requires only simple dissecting tools, and has minimal impact on live fish when properly done. However, ageing fish with scales does have disadvantages (Mackay *et al*, 1990). Many fish have the ability to re-absorb scales or produce new scales to replace lost ones resulting in growth patterns that do not accurately reflect the age of the fish. As well, scales from older fish, are very difficult to read and interpret, and thus fin rays and otoliths are the preferred structures for ageing difficult groups. Confirmation of ages based on length, and separation of older age classes was undertaken by scale circuli analysis.

Scales were removed by gently scraping against the grain of the scales with the blade of a clean scalpel. Large scales were removed with small forceps. Since any one scale may not accurately represent the true age of the fish, several scales (5) were collected from each fish. Scales were deposited directly onto a slide that had been labelled, covered with a second slide, and taped together

4.3.12 Age reading using circuli

Fish ages were determined by viewing scales with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses. Because of the known difficulty in ageing coarse fish with scales, two different readers read all scales. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or the lengths of the specimens, and assigned a final age to the fish. Circuli on perch, smelt, sea bass, roach and dace scales were determined by several events, "crossing over" and circuli disruption. Primarily, "crossing over" in the lateral margins near the posterior\anterior interface of the scale was used to determine the origin of the circular. Here compressed circuli "cross over" the previously deposited circuli of the previous year's growth. Typically annuli of the first three years were observed transversing this interface as dark bands. These bands remained consistent throughout the posterior field and rejoined the posterior\anterior interface on the opposite side of the focus. Annuli were also observed in the anterior lateral field of the scale. Here the annuli typically revealed a pattern of discontinuous and suddenly breaking segmented circuli. This event was also distinguished by the presence of concentric white lines, which were typically associated with the disruption of circuli. Annuli were also observed bisecting the perpendicular plain of the radial striations in the anterior field of the scales. Radii emanated out from the focus of the scale towards the outer corner margins of the anterior field. These radial striations consist mainly of segmented concave circuli. The point of intersection between radii and annuli results in a "straightening out" of the concave circuli. This straightening of the circuli should be consistent throughout the entire anterior field of the scale. This event is further amplified by the presence of concave circuli neighbouring both directly above and below the annulus. The first year's annulus was difficult to locate on some scales. It was typically best identified in the lateral field of the anterior portion of the scale. The distances from the focus to the first year's annulus were moderate with respect to the following three annuli, demonstrating slightly reduced amount of growth proportional to the first. When ageing young coarse fish, zero through age two, extreme caution was taken as not to over age the structure. Young fish have no point of reference to aid in the determination of the first year; this invariably results in over examination of the scale and such events as hatching or saltwater incursion marks (checks) may be interpreted as the first year. Figure 4.5 is the scale of a six year old sea bass captured in Grays as seen under a standard microscope. Its shows the contrasting growth rings (circuli)

Figure 4.5 The Scale of 5+ sea bass captured at Grays site in December 2000 indicating the annual growth rings (circuli). Picture taken by a Sigma 300mm macro lens attached to a Canon EOS5 camera



4.4 Fish data analysis methods

Various statistical methods were used to analyse the fish datasets. They comprised methods that describe community structure namely: species richness, Gibbs-Martin Index of diversity, population density, cluster analysis, cumulative frequency (percentage) of occurrence curves (Lorenz curves), and species dominance or concentration index. The data on populations of fish caught were analysed for each site and subsequently pooled for each zone. Semi quantitative comparisons were performed for sites along the Thames and its associated habitats. Comparisons of species composition and relative abundances within each zone were made.

Four aspects of the fish survey results were examined in detail:

1. Variation in species distribution between sites.
2. Variation in the numbers of individuals i.e. population sizes between sites and seasons.
3. Variation in the community structure in different sites
4. Variation in age structure in different sites and seasons

4.4.1 Community Structure

This type of analysis allowed the exploration of similarities and differences in the community structure which might be explained by the habitat types and physico-chemical conditions related to the habitat position in the estuary. A classic view of estuarine communities is that species diversity is very high at the marine end of the estuary and falls to a low level in the mid-estuary where marine species cannot tolerate the reduced salinity and freshwater species cannot tolerate the raised salinity. Diversity then increases towards the head of the estuary where freshwater species predominate but are less diverse than the essentially marine community at the mouth of the estuary (Wheeler, 1979; Day *et al* 1989).

It is also generally perceived that estuaries are biologically productive so that reduced species diversity may be accompanied by very large population sizes of the species that can tolerate the variable physical and chemical nature of the habitat. Although the exact species and dominance rank changes from site to site and zone to zone, the dominant fish species actually come from only a few taxonomic groups. Important families for the Thames Estuary system are Pleuronectidae, Cyprinidae, Gobiidae, Gasterosteidae, Serranidae and Osmeridae. In order to investigate these concepts in relation to the Thames Estuary and its associated docks and creeks and tributaries, the data collected from the various sites was subjected to an analysis of community structure. Community structure is defined in this study as the dispersion of species.

4.4.2 Species Richness

A list of all the species captured from a specific ecological zone provides a description of the fish species richness for that environment.

4.4.3 The Gibbs-Martin Index of species diversity

This is an index used to depict local community diversity. This index was first used in 1962 by Martin and Gibbs (1962) in a completely different context. Gibbs and Martin (1962) used this index to test the diversification of employment in different industries in regions within the United Kingdom but the index has subsequently been used in a wide variety of situations. In this study the Gibbs-Martin index was used to depict biological diversification in fish communities or biological categories. The formula for calculating the index is:

GBi = 1- $(\sum x^2)/(\sum x)^2$, Where

GBi is the Gibbs-Martin index of species diversity and **x** is the number of individuals of each species.

If a fish community is made up of only one species the index is 0. If many species are evenly distributed in terms of abundance the index approaches 1.

4.4.4 Population Density

Total density is the term used to describe the total number of organisms obtained from pooling all the species in a site, zone or the entire region. Population density describes the number of individuals of a species per unit area or volume. Out of these statistics many other variables can be derived (Fowler *et al*, 2003). The seine net method employed does not provide absolute densities as the sampled area and capture efficiency is unknown. However, careful replication of the sampling procedure means that the number of individuals captured provides a measure of relative density or abundance.

4.4.5 Percentage frequency of occurrence

Percentage frequencies of occurrences (% proportions) are derived variables. A proportion is the ratio of a part to the whole. Frequencies of occurrence are based on counts of individual species and are derived as the ratio of the number individuals of a particular species in a site/zone/season to the total number of individuals of all species.

4.4.6 Graphical analysis

These analyses provide a visual way of comparing values for abundances and community structure for different sites or zones. They comprise circle or pie graphs, cluster graphs and Lorenz curves.

4.4.7 Circle or Pie graphs

The pie graph is best suited for displaying data which are percentages or proportions. If the area of a circle is regarded as 100% it can be divided into sectors (the slices of the pie) which correspond in size to each individual percentage or proportion making up the total. When the number of categories (species/sites) in a pie graph is large or when some of the slices are very narrow pie graphs can become cluttered and difficult to interpret. To overcome such a problem a "bar of pie" with user defined values extracted and combined into stacked bar can be used.

4.4.8 Cluster analysis - cluster graphs

The objective of cluster analysis is to sort the cases under consideration into groups such that the degree of association is high between members of the same group and low between members of different groups (Mardia *et al* 1979). Biological data can often be expected to have a hierarchical structure (Digby and Kempton, 1987) and some of the more frequently used forms of cluster analysis involve hierarchical techniques. Cluster Analysis is a multivariate analysis technique that seeks to organise information about variables so that relatively homogeneous groups, or "clusters," can be formed. The clusters formed with this family of methods should be highly internally homogenous (members are similar to one another) and highly externally heterogeneous (members of one cluster are not like members of other clusters (Aldenderfer and Blashenfield 1984). Although cluster analysis is relatively simple, and can use a variety of input data, it is a relatively new technique and is not supported by a comprehensive body of statistical literature. So, most of the guidelines for using cluster analysis are rules of thumb and some authors caution that researchers should use cluster analysis carefully in order to avoid the pitfall of over-interpreting the results, (e.g. Kim, Mueller and Charles, 1978 and Hair, 1992). The main outcome of a cluster analysis is a dendrogram, which is also called a tree diagram. Clustering techniques have been applied to a wide variety of research problems. Everitt, (1974) provides an excellent summary of the published studies reporting the results of cluster analyses For the purpose of this study, fish species-sites results were clustered using Minitab 13 for Windows software (Minitab Inc., 2000) by an agglomerative hierarchical clustering using a complete linkage algorithm to derive associations between fish species in terms of their habitat occupancy. The results of the graphical analysis are displayed in a cluster graph called a dendrogram.

4.4.9 The Lorenz curves

The Lorenz curves were first used by Lorenz (1905) in the financial market to visually show differences in wage distribution in the population but these curves can also be applied in different fields. In this study they have been used to show differences in the dispersion of species in the estuarine fish population. The curves are cumulative frequencies of occurrence (%) curves and are derived from plotting cumulative frequency (sum of the frequency of occurrence of each species in a site) against species rank (species ranked in order of frequency of occurrence). These curves and quantitative measures were then used to examine and compare the extent to which species distribution differed from other sites, or general region. Their main functions are as follows:

1. they show the visual effect of species concentration
2. they are useful for comparing the relative concentration, or dispersion of populations areally
3. Comparison of the curves with the straight line of even distribution is a quick visual means of describing (in this particular study) regional or locality species diversity

4.4.10 Index of species dominance or species concentration (*Icon*)

Visual examination of frequency of occurrence curves allows only a relatively superficial interpretation. The numerical index based on the sum of the cumulative frequency of occurrence curves (known as the Index of Species Concentration or Species dominance) gives greater precision (Hammond and McCullough 1978). The index was calculated by:

$Icon = (A - R) / (M - R)$, where

Icon is the index of species concentration (or species dominance);
A is the site cumulative percentage total of the species;
M is the number of species multiplied by 100 and represents a hypothetical monospecific scenario where each sample contains only one species but several species are present at a Zone or region and.
R is the regional cumulative percentage total of the species.

The crude index therefore is a measure of the extent to which any site, included in the whole region surveyed, differs from the absolute concentration of frequencies into one species. The index was then used to compare the river sites with the entire estuary in which they are situated. Hence the diversity of species in Hammersmith, Battersea, Greenwich, Belvedere and Grays were more realistically compared with the existing structure in the entire region surveyed instead of some hypothetical extreme. This is done again by using the cumulative totals. Each site is compared to the entire region surveyed (zones 1 and 2) as a whole taking the index for the whole zone as base-line 0.00.

4.5 Results

The primary data from the monthly fish survey of the six sites on the main river are given in Tables 4.1 - 4.8 and in Appendix 4 Tables 1-12 and are presented and described for the main river in the following sections. Tables 4.16, 4.18 and 4.19 are the fish results of the surveys for the Dartford Creek, Queen Victoria Dock Basin and the East India Dock Basin. Appendix 4 are the results for the 0+ and 1+ fish aged using circuli analyses and length frequencies as described in Page - 106 - to - 110 -. From these tables the data have been abstracted and used to illustrate the total densities and variation in the fish species distribution and relative abundance at different sites and months together with the difference in age structure of the fish at different sites and seasons. The results are presented firstly for the main river and then for the additional habitats. Age analysis was only carried out on samples from the upper and middle Thames Estuary because fish capture in the East India Basin constitute primarily young of the year individuals of common goby, dace and smelt three-spined stickleback and the post larvae of flounder. In the Queen Victoria Basin fish species were too few as 75.1% of all fish capture was made up of one species (sand smelt). As for the Dartford Creek, fish data were not classified into age groups by the Environment Agency.

Following these analyses, variation in community structure at the different sites was considered for all the sampled habitats using cluster analysis and species concentration analysis using Lorenz or cumulative frequency of occurrence curves and the Index of species Concentration (Icon) model described in section 4.4.9 page - 115 - (Lorenz, 1905). Diversity analysis was carried out using the Gibbs-Martin Index of species diversity.

4.5.1 Species captured in the upper and mid Thames Estuary

Table 4.1 is a list indicating the fish species captured from the main river sites; a total of 26 species were recorded, including Whiting (*Merlangius merlangius*) which is an unusual species in the Thames estuary (Colclough, 1992 & 2001; Colclough *et al* 1998 and 1999). Twenty one species were recorded in the upper estuary (Zone 1) and 21 in the mid estuary (Zone 2) although two sites in the mid estuary, Belvedere and Grays lacked complete annual fish datasets. Sixteen species were common to both the upper and mid estuary. The total of 26 species represents 14 families of teleosts, including one cyprinid crossbreed (roach x bream). The most abundant family recorded in this study in the tidal Thames was the Cyprinidae, with 8 species occurring mainly in the upper estuary. In the middle estuary, the far greater contribution came from marine species although all families recorded in the tidal Thames except Cottidae were present. Amongst the 26 species recorded in Zones 1 and 2 of the estuary 21 species were recorded in Zone 1 and 21 were recorded in Zone 2. Sixteen species were common to Zones 1 and 2 whilst 5 were restricted to Zone 1 and only 2 were restricted to Zone 2.

Table 4.1 Fish species captured from sites along Zones 1 and 2 of the Thames Estuary by a 4mm knotless seine net from May 2000 to April 2001

Common name	Latin Name	Tedd	Hamm	Batt	Green	Belve	Grays
Roach	*Rutilus rutilus*	X	X	X	X	X	
Flounder	*Platichthys flesus*	X	X	X	X	X	X
3-Spined s,bk	*Gasterosteus aculeatus*	X	X	X	X	X	
Dace	*Leuciscus leuciscus*	X	X	X	X	X	
Sea Bass	*Dicentrarchus labrax*		X	X	X	X	X
Bream	*Abramis brama*	X	X	X	X	X	
Common goby	*Pomatoschistus microps*	X	X	X	X	X	X
Smelt	*Osmerus eperlanus*			X	X	X	X
Sand smelt	*Atherina presbyter*		X	X	X	X	X
Perch	*Perca fluviatilis*	X	X	X	X	X	
Chub	*Leuciscus cephalus*	X		X			
Sand Goby	*Pomatoschistus minutus*	X		X	X		X
10-Spine s,bk	*Pungitius pungitius*				X	X	
15-Spine,sbk	*Spinachia spinachia*				X	X	
Eel	*Anguilla anguilla*		X	X	X	X	
Grey Mullet	*Mugil labrosus*		X	X	X	X	X
Bleak	*Alburnus alburnus*	X	X			X	
Barbel	*Barbus barbus*				X	X	
Dab	*Limanda limanda*		X	X	X	X	X
Place	*Pleuronectes platessa*		X	X	X	X	X
Gudgeon	*Gobio gobio*	X	X				
Minnow	*Barbus barbus*	X	X				
Herring	*Clupea harengus*						X
Whiting	*Merlangius merlangius*						X
Bull head	*Cottus gobio*	X					
Roach'Bream	*Roach & bream hybrid*	X					
	Number of species	**14**	**16**	**16**	**18**	**18**	**11**

Marine-estuarine dependent species
Species captured in Zone 1
Species captured in Zone 2
Freshwater species

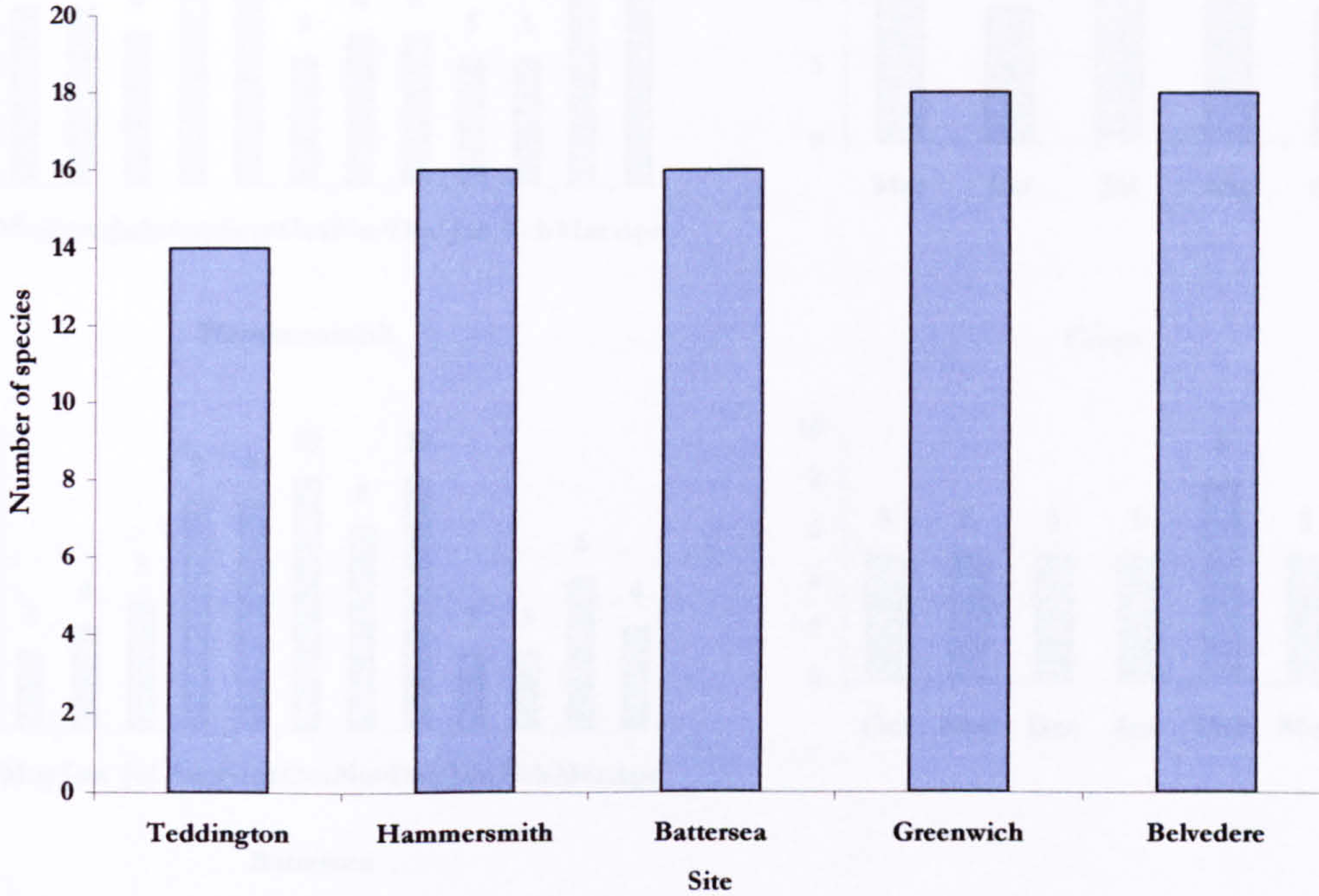
Total = 26 species
No of species recorded Zone 1 only = 5
No of species recorded in Zone 2 only = 2
No. of species recoded in Zone 1 = 21 species; Zone 2 = 21 species
Number of species common to Zones 1 and 2 = 16

Fish recorded in the upper and middle Thames Estuary included 14 marine-estuarine dependent species (Table 4.1) namely herring (*Clupea harengus*), plaice (*Pleuronectes platessa*), dab (*Limanda

limanda), mullet (*Mugil cephalus*), eel (*Anguilla anguilla*), 10-spined stickleback (*Pungitius pungitius*) 15-spined stickleback (*Spinachia spinachia*), sand goby (*Pomatoschistus minutus*), sand smelt (*Atherina presbyter*), smelt (*Osmerus epalanus*), sea bass (*Dicentrarchus labrax*), flounder (*Platichthys flesus*), common goby (*Pomatoschistus microps*) and whiting (*Merlangius merlangus*). These 14 species dominated the middle estuary in varying numbers from one site to the other. Smelt for example are particularly abundant in Belvedere whilst sea bass 1+ were dominant at Greenwich (Table 4.6) and Grays (Table 4.8) although Grays was only sampled in the winter months. Herring, 15-spined stickleback and whiting were only found in the mid Estuary. More typically freshwater species namely: roach (*Rutilus rutilus*), dace (*Leuciscus leuciscus*) bream (*Abramis brama*), perch (*Perca fluviatilis*), bleak (*Alburnus alburnus*)) were dominant in the upper estuary but were also found in the mid estuary. Chub (*Leuciscus cephalus*), gudgeon (*Gobio gobio*), minnow (*Phoxinus phoxinus*) and bullhead (*Cottus gobio*) were exclusive to the upper estuary. Migratory species namely: eel (*Anguilla anguilla*), flounder (*Platichthys flesus*) and smelt (*Osmerus eperlanus*)) were common in both zones. Three-spined sticklebacks (*Gasterosteus aculeatus*) and common goby (*Pomatoschistus microps*) could be regarded as estuarine resident species as they were present throughout the estuary at all seasons and also breed there. Some species had a very restricted distribution in the estuary. For example the bullhead (*Cottus gobio*) is an obligate freshwater inhabitant and this species was only caught in Teddington during fast flows.

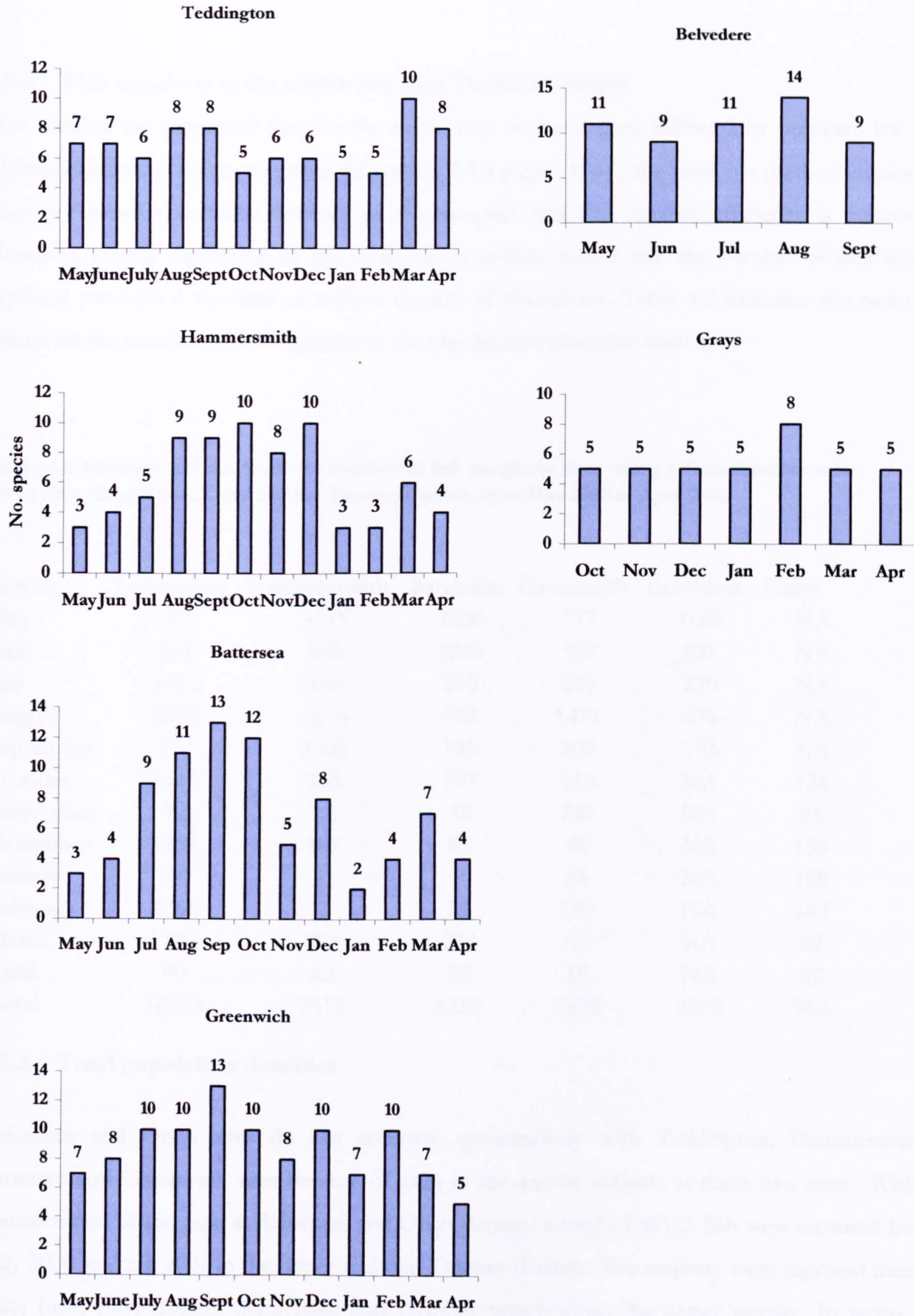
Figure 4.6 shows the number of species captured in the summer surveys for three Zone 1 sites (Teddington, Hammersmith and Battersea) and two Zone 2 sites (Greenwich and Belvedere).

Figure 4.6 Number of species captured in the summer months on sites along Zones 1 and 2 of the Thames Estuary.



Grays is not included in the summer species evenness analysis because of its lack of summer dataset. Overall, it is noted that Species richness is higher in the mid estuary sites than those of the upper estuary sites but these differences are not very pronounced. The monthly and seasonal changes in species richness can be viewed in more details in Figure 4.7 which shows the number of species captured monthly at the main river sites. Teddington displays an interesting variation in its species richness. The range between months is 5. The highest species richness occurs between spring and summer, from the months of March to September and the values are lower from mid fall through winter (October to February). The Hammersmith site displays a near bell shaped monthly species distribution with a peak in the summer months. The species richness range between months is 7. Battersea and Greenwich displays a similar pattern of species distribution in the spring but not in winter. In winter Greenwich displays higher species richness than Battersea. Belvedere shows species evenness values typical of Battersea and Greenwich. Grays displays unvarying richness values with a surprising rise in February. Overall the highest species richness values occur in the summer season and the lowest values occur in the winter months.

Figure 4.7 Number of species captured monthly on main river sites



4.5.2 Fish numbers in the upper and mid Thames Estuary

Fish number are presented first for the main river sites and then followed by numbers for the additional habitats. As stated earlier (in section 4.4.4 page - 114 -) the seine net method employed does not provide absolute densities as the sampled area and capture efficiency is unknown. However, careful replication of the sampling procedure means that the number of individuals captured provides a measure of relative density of abundance. Table 4.2 indicates the monthly results for the number of fish captured in the sites located along the main river

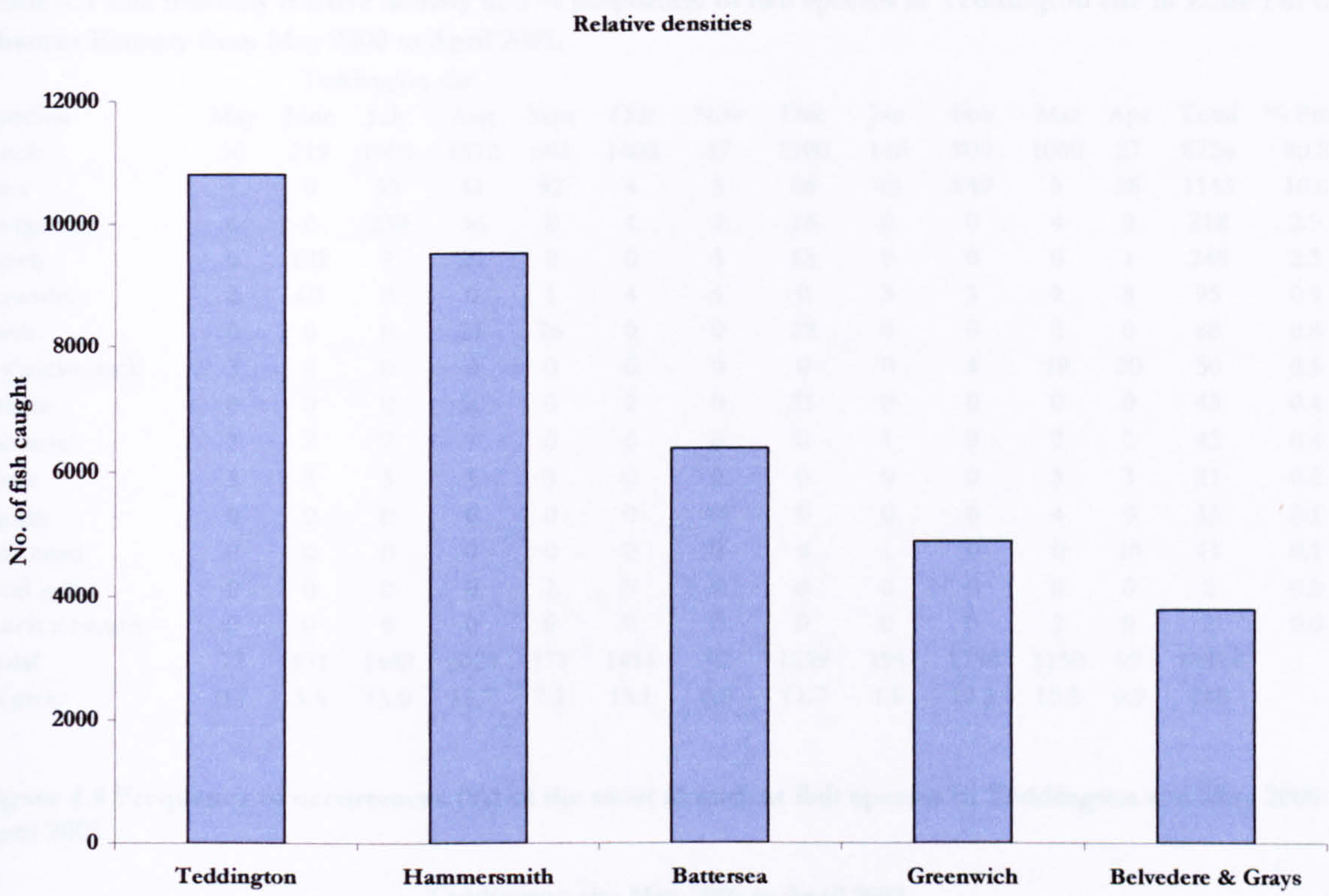
Table: 4.2 Monthly and site totals for number of fish caught in sites using a 4mm knotless seine net in sites along Zones 1 and 2 of the Thames Estuary from May 2000 to April 2001.

Month	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays
May	72	3175	2230	777	1069	NA
June	591	945	2260	557	831	NA
July	1402	410	370	298	279	NA
August	2024	1676	668	1471	678	NA
September	777	2302	195	505	153	NA
October	1411	365	197	616	NA	136
November	92	72	36	241	NA	85
December	1259	187	86	85	NA	159
January	191	11	9	66	NA	109
February	1756	7	22	189	NA	142
March	1130	304	234	53	NA	69
April	99	62	50	18	NA	62
Total	10804	9516	6357	4876	3010	762

4.5.3 Total population densities

Belvedere and Grays sites do not compare quantitatively with Teddington, Hammersmith, Battersea and Greenwich sites because of gaps in the annual datasets at these two sites. With a consideration of the gaps in Belvedere and Grays datasets a total of 35325 fish were captured from May 2000 to April 2001 in the upper and mid Thames Estuary. The majority were captured during May, June, July, August, September and October mostly from the upper estuary. In terms of numbers the total number of fish captured in each site with a complete annual dataset along the upper and mid Thames Estuary were: Teddington (10804); Hammersmith (9516); Battersea (6357); Greenwich (4876); Belvedere (with 5 warm months datasets = 3010) and Grays (with seven months, mostly cold months data = 1969). Observations based on Teddington, Hammersmith, Battersea and Greenwich indicates that the relative population density declines downstream (Figure 4.8). Figure 4.8 is a column graph showing the total number of fish captured in the whole year in four main river sites with complete annual datasets (data for Grays and Belvedere sites combined).

Figure 4.8 Total number of all fish captured from 4 main sites along the Thames Estuary



It is clear from Figure 4.8 that the annual total number of fish caught during the year declined downstream from Teddington. On the other hand species richness increased downstream (Figure 4.6). This trend of fish species and population distribution in the upper and middle Thames Estuary is contrary to the trend observed for the invertebrates' distribution in the previous chapter. The reasons for these differences in species distribution trends between fish and macroinvertebrates will be discussed in the discussion chapter.

4.5.4 Main River - Variation in number of species and individuals between sites

Upper estuary

Twenty six species were recorded during the monthly surveys of the main river; several species were caught only occasionally or were not very abundant in the samples. Figure 4.3 to 4.8 show the number of fish belonging to each species caught at each site along the main river.

Teddington

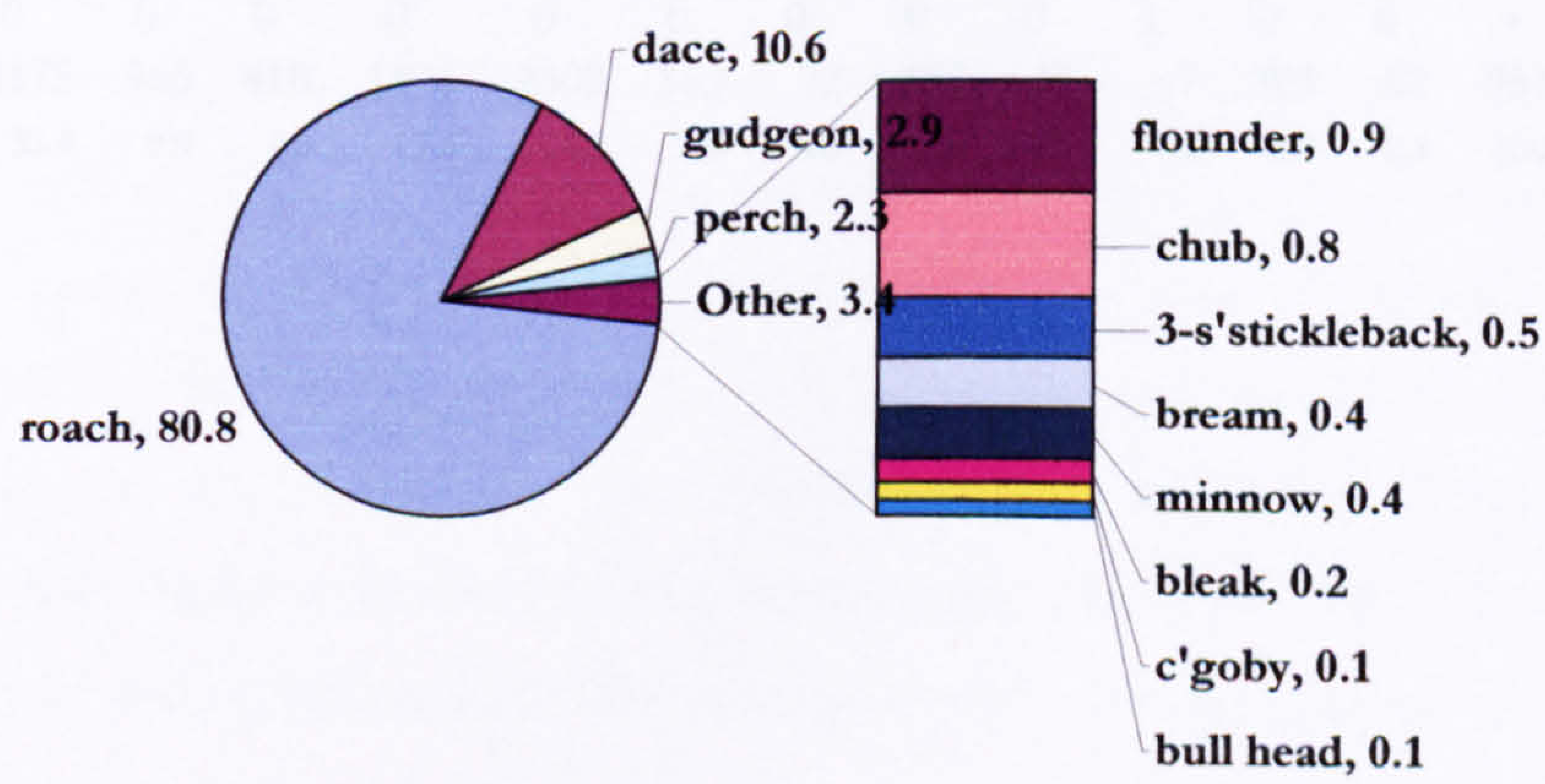
The Numbers and relative abundances of the 14 species caught at Teddington are shown in Table 4.3 and are presented as a pie chart in Figure 4.9. The dominant species in Teddington site was roach (80.8%) followed by dace (10.6%). Other species including gudgeon and perch were abundant but much less dominant as percentage proportions of (2.9%, 2.3% respectively). Flounder was present in a very small proportion (0.9%) and was the only species of marine origin.

Table 4.3 The monthly relative density and % proportion of fish species in Teddington site in Zone 1 of the Thames Estuary from May 2000 to April 2001.

	Teddington site													
species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	% Prop
roach	50	319	1098	1872	683	1400	57	1100	140	900	1080	27	8726	80.8
dace	1	0	55	41	52	4	5	66	46	840	5	28	1143	10.6
gudgeon	6	6	230	36	8	1	9	18	0	0	4	0	318	2.9
perch	0	192	9	24	2	0	5	15	0	0	0	1	248	2.3
flounder	2	60	0	0	1	4	5	0	3	3	9	8	95	0.9
chub	0	0	0	21	26	0	0	39	0	0	2	0	88	0.8
3-s'stickleback	3	4	0	0	0	0	0	0	0	4	19	20	50	0.5
bream	0	0	0	20	0	2	0	21	0	0	0	0	43	0.4
minnow	7	7	7	7	0	0	0	0	1	9	2	2	42	0.4
bleak	3	3	3	3	3	0	0	0	0	0	3	3	21	0.2
c'goby	0	0	0	0	0	0	11	0	0	0	4	0	15	0.1
bull head	0	0	0	0	0	0	0	0	1	0	0	10	11	0.1
sand goby	0	0	0	0	2	0	0	0	0	0	0	0	2	0.0
roach x bream	0	0	0	0	0	0	0	0	0	0	2	0	2	0.0
Total	72	591	1402	2024	777	1411	92	1259	191	1756	1130	99	10804	
% prop	0.7	5.5	13.0	18.7	7.2	13.1	0.9	11.7	1.8	16.3	10.5	0.9	100	

Figure 4.9 Frequency of occurrences (%) of the most abundant fish species in Teddington site May 2000 to April 2001

Teddington site May 2000 to April 2001



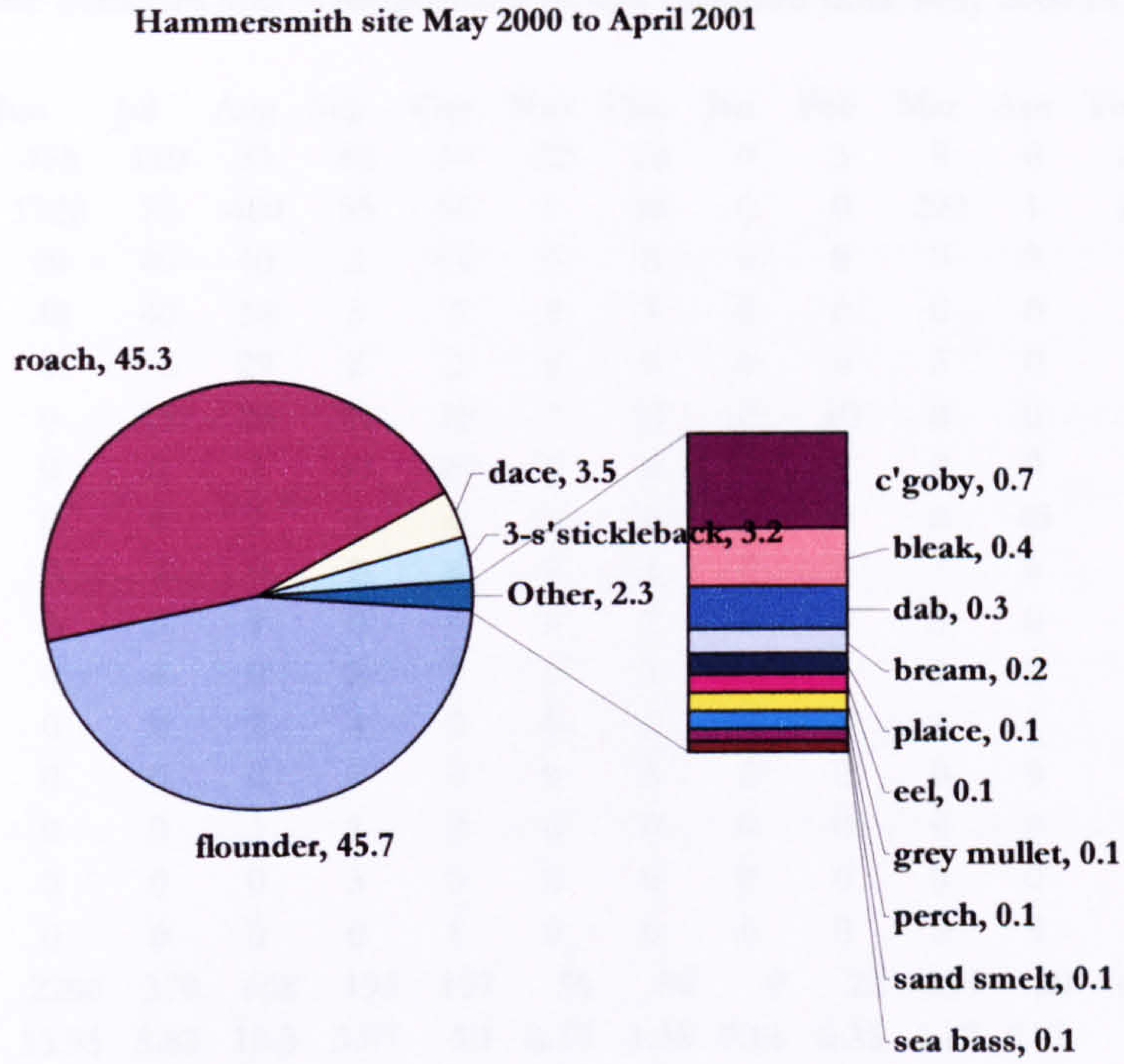
Hammersmith Bridge

The number and relative abundance of the 16 species caught at Hammersmith are shown in Table 4.4 and Figure 4.10. The most abundant species in Hammersmith site was flounder (45.7%). However, as will be discussed later these were primarily 0+ year class which were recorded in the months of May, June and July. This is the breeding period for this estuarine-marine dependent fish. The second most abundant species recorded in Hammersmith site was roach (45.3%). Dace and the Three-spined stickleback were present most of the year but in relatively small percentages (3.5% and 3.2% respectively). Marine species comprising sea bass, sand smelt, eel, Grey mullet, dab and place were recorded although not in large numbers. The presence of these marine species in Hammersmith site is an indication that, although the site is in Zone 1, it has a marine influence.

Table 4.4 The monthly relative densities and % proportions of fish captured from Hammersmith site in Zone 1 of the Thames Estuary

species	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	% prop.
flounder	3162	845	180	41	70	3	3	36	0	0	0	6	4346	45.7
roach	9	62	170	1426	2190	283	29	112	0	0	27	0	4308	45.3
dace	0	17	0	4	0	4	2	4	0	0	270	30	331	3.5
3-s'stickleback	4	21	50	149	4	48	13	14	3	0	0	0	306	3.2
c'goby	0	0	0	25	6	11	8	6	7	4	0	0	67	0.7
bleak	0	0	0	9	4	0	0	4	0	0	1	23	41	0.4
dab	0	0	0	15	15	0	0	0	0	0	0	0	30	0.3
bream	0	0	0	6	1	5	0	2	0	0	3	0	17	0.2
plaice	0	0	0	0	10	0	0	3	1	0	0	0	14	0.1
eel	0	0	0	1	2	3	1	1	0	0	2	3	13	0.1
grey mullet	0	0	0	0	0	0	13	0	0	0	0	0	13	0.1
perch	0	0	5	0	0	1	0	5	0	0	1	0	12	0.1
sand smelt	0	0	0	0	0	6	3	0	0	0	0	0	9	0.1
sea bass	0	0	5	0	0	1	0	0	0	0	0	0	6	0.1
gudgeon	0	0	0	0	0	0	0	0	0	2	0	0	2	0.0
minnow	0	0	0	0	0	0	0	0	0	1	0	0	1	0.0
Total	3175	945	410	1676	2302	365	72	187	11	7	304	62	9516	
% prop	33.4	9.9	4.3	17.6	24.2	3.8	0.8	2.0	0.1	0.1	3.2	0.7	100.0	

Figure 4.10 Frequencies of occurrences (% proportions) of the most abundant fish species at Hammersmith site May 2000 to April 2001



Battersea site

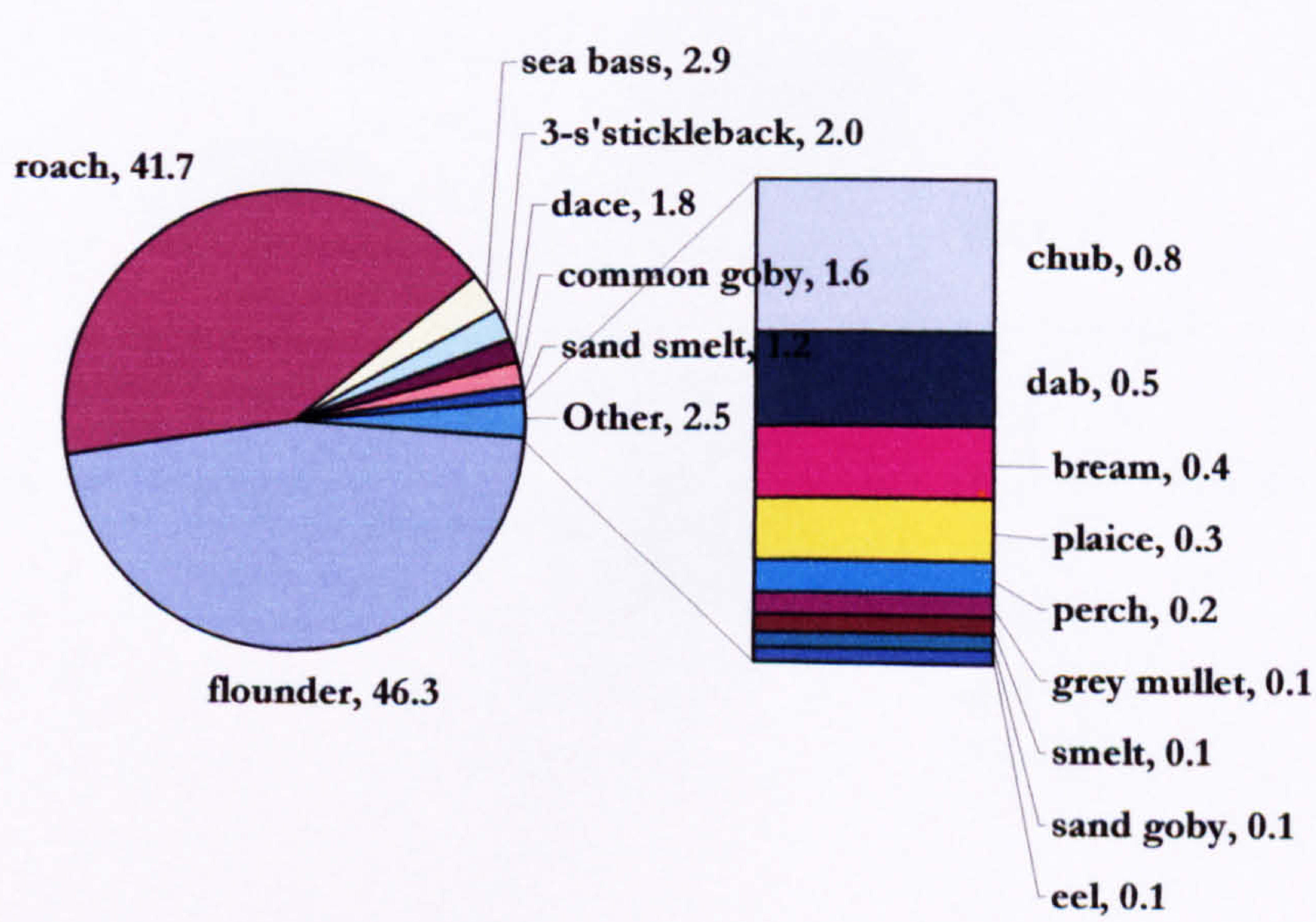
The number and relative abundance of the 16 species captured at Battersea are shown in Table 4.5 and the frequency of occurrence for each species in Figure 4.11. The Battersea catch consisted of a mixture of freshwater and marine species. The dominant species recorded in Battersea site was flounder (46.3%) followed by roach (41.7%). Battersea and Hammersmith sites are geographically close (see Figure 2 Chapter 2). Again as in Hammersmith site the highest records for flounder occurred in the months of May, June and July also reflecting the breeding period of this fish. Apart from roach other freshwater species (dace, bream and perch) were recorded but in small numbers. The proportion of marine species increased to include other marine and estuarine-marine dependent species comprising sea bass (2.9%), three-spined stickleback (2%), common goby (1.6%), sand smelt (1.2%), dab (0.5%), plaice (0.3%), eel (0.1%) and grey mullet (0.1%), Although roach, a freshwater species was recorded in high numbers, in fact the number of marine species recorded was now greater than the number of freshwater species. This site is clearly the transitional zone between the upper and middle estuary. The importance of freshwater species is diminishing gradually.

Table 4.5 Monthly relative densities and % proportions of fish captured from May 2000 to April 2001

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	% prop
flounder	2214	458	119	33	45	19	22	23	0	3	9	0	2945	46.3
roach	12	1722	70	480	55	66	1	36	0	0	209	1	2652	41.7
sea bass	0	40	40	40	2	60	0	0	0	0	0	0	182	2.9
3-s'stickleback	4	40	40	34	5	3	0	3	0	0	0	0	129	2.0
dace	0	0	78	29	2	2	0	0	0	0	5	0	116	1.8
common goby	0	0	13	29	21	10	7	11	0	10	0	0	101	1.6
sand smelt	0	0	0	7	47	20	0	0	0	0	0	0	74	1.2
chub	0	0	0	2	4	0	0	0	0	0	0	45	51	0.8
dab	0	0	1	0	2	6	3	5	7	5	1	0	30	0.5
bream	0	0	5	9	0	5	0	2	0	0	3	0	24	0.4
plaice	0	0	4	0	2	3	3	1	0	4	3	0	20	0.3
perch	0	0	0	2	4	0	0	0	0	0	4	1	11	0.2
grey mullet	0	0	0	0	0	0	0	5	2	0	0	0	7	0.1
smelt	0	0	0	3	1	2	0	0	0	0	0	0	6	0.1
sand goby	0	0	0	0	5	0	0	0	0	0	0	0	5	0.1
eel	0	0	0	0	0	1	0	0	0	0	0	3	4	0.1
Total	2230	2260	370	668	195	197	36	86	9	22	234	50	6357	
% prop	35.08	35.55	5.82	10.5	3.07	3.1	0.57	1.35	0.14	0.35	3.68	0.79		
Eveness	3	4	9	11	13	12	5	8	2	4	7	4	16	

Figure 4.11 Frequency of occurrence (% proportions) of the most abundant fish species in Battersea site May 2000 to April 2001

Battersea site May 2000 to April 2001



4.5.5 Mid Thames Estuary (Zone 2)

Three sites comprising Greenwich, Belvedere and Grays were sampled in Zone 2 the brackish water portion of the estuary.

Greenwich

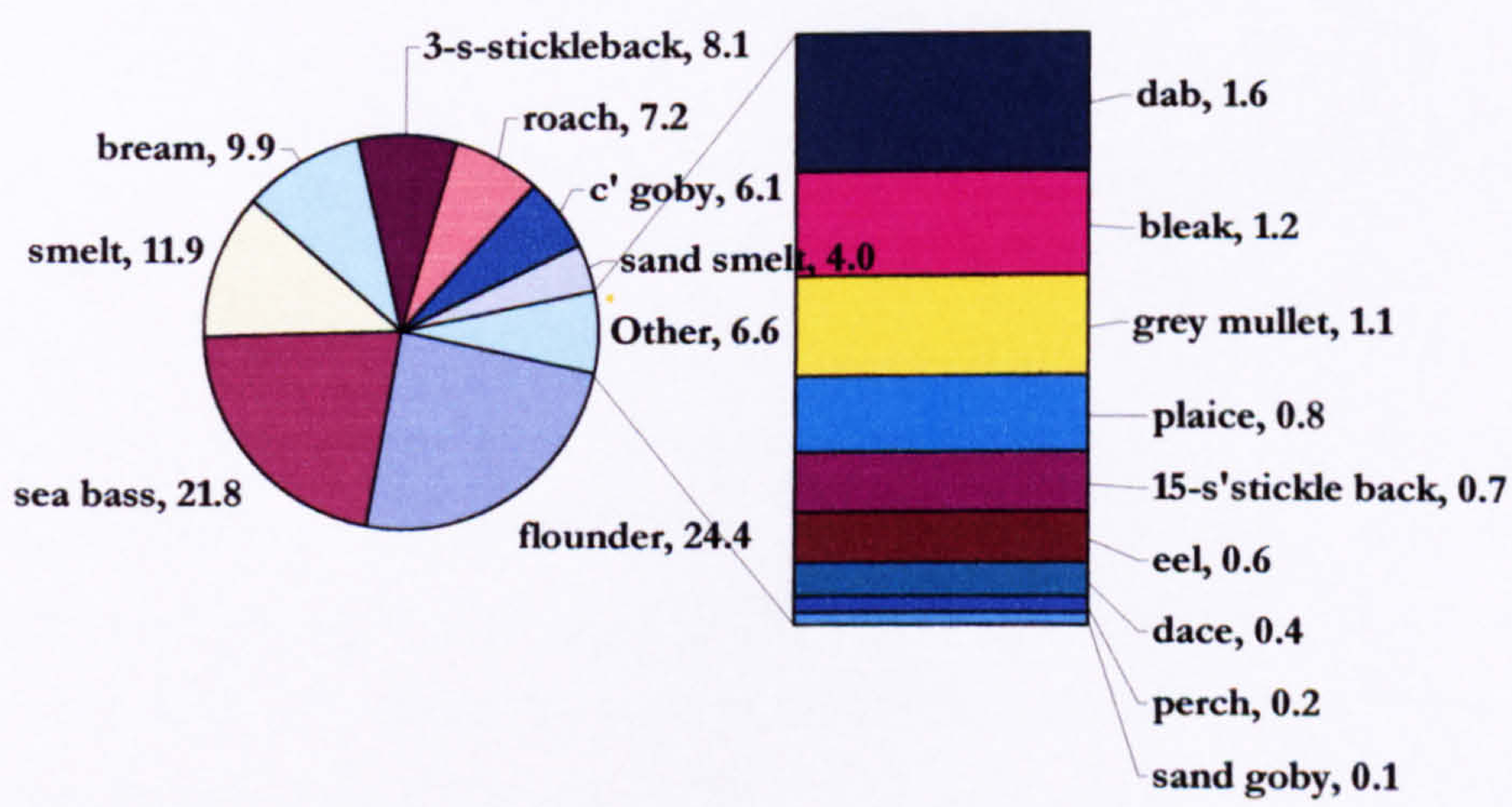
The number and relative abundance of the 18 fish species caught at Greenwich are shown in Table 4.6 and their frequency of occurrence in Figure 4.13. Eighteen species of fish were recorded in Greenwich and 13 of these species were of marine origin (see Table 4.1). The dominant species at Greenwich was flounder (24.4%), followed by sea bass (21.8%) and Smelt (11.9%). Unlike the previous sites Greenwich sites had a more even species distribution, with no one species dominating the site. Other species, namely: bream, three-spined stickleback, roach, common goby, sand smelt and dab were present in the annual percentage proportions of 9.9%, 8.1%, 7.2%, 6.1%, 4.0% and 1.6% respectively. Roach, bream and flounder were present throughout the year.

Table 4.6 The monthly relative density and % proportions of fish captured from Greenwich site in Zone 2 of the Thames Estuary from May 2000 to April 2001

Species	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	% prop
flounder	708	222	30	32	64	21	18	14	5	65	7	2	1188	24.4
sea bass	0	200	240	360	22	99	140	1	0	0	0	0	1062	21.8
smelt	1	3	7	438	118	5	0	8	0	0	0	1	581	11.9
bream	3	5	4	0	11	361	51	10	0	33	4	0	482	9.9
3-s-stickleback	39	77	5	270	3	0	0	0	0	0	0	0	394	8.1
roach	23	43	2	32	95	48	6	16	28	51	6	2	352	7.2
c' goby	0	0	0	270	15	0	0	4	0	8	0	0	297	6.1
sand smelt	1	3	0	0	118	46	0	0	6	0	22	0	196	4.0
dab	0	0	0	9	0	2	18	21	13	8	4	1	76	1.6
bleak	0	0	0	55	2	0	0	0	0	0	0	0	57	1.2
grey mullet	0	0	4	0	16	23	0	2	6	4	0	0	55	1.1
plaice	0	0	1	2	6	9	5	8	2	8	0	0	41	0.8
15-s'stickle back	0	0	0	0	32	0	0	0	0	0	0	0	32	0.7
eel	0	0	3	0	0	0	1	0	0	4	8	12	28	0.6
dace	2	4	0	0	3	2	2	1	0	5	0	0	19	0.4
perch	0	0	0	3	0	0	0	0	6	0	0	0	9	0.2
sand goby	0	0	0	0	0	0	0	0	0	3	2	0	5	0.1
9-s'stickle back	0	0	2	0	0	0	0	0	0	0	0	0	2	0.0
Totals	777	557	298	1471	505	616	241	85	66	189	53	18	4876	
% prop	15.9	11.4	6.1	30.2	10.4	12.6	4.9	1.7	1.4	3.9	1.1	0.4		

Figure 4.12 Frequency of occurrence (% proportions) of fish captured from Greenwich site May 2000 to April 2001

Greenwich Site May 2000 to April 2001



Belvedere

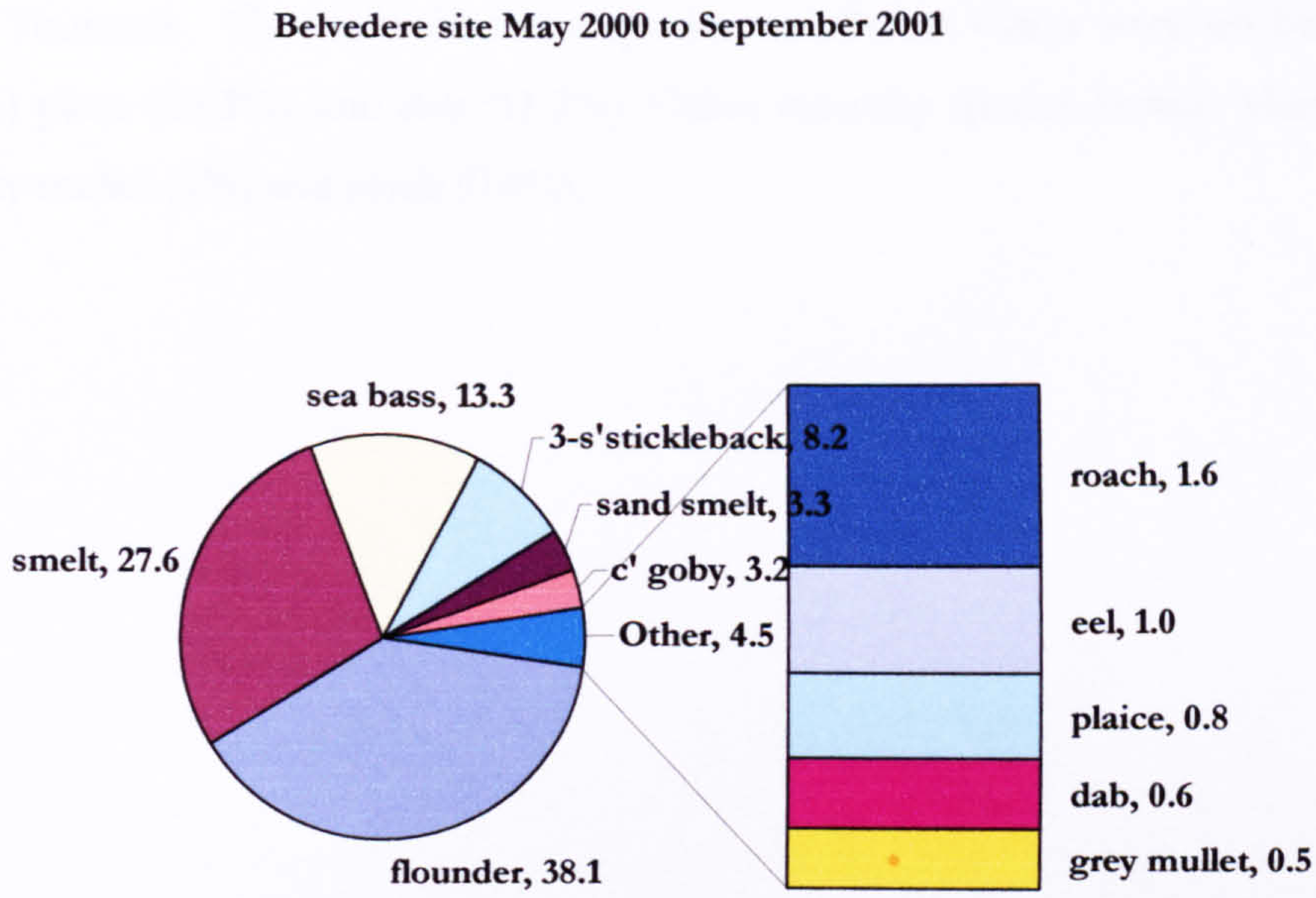
Eighteen fish species were recorded at this site, representing all the common species found in the mid estuary. Although Belvedere site cannot be quantitatively compared with the previous sites because of the shorter period of sampling undertaken at the site, it can be compared qualitatively with the previous sites. This is because the fish data collected from May to September provided sufficient information about the mid estuary habitat it represents with respect to species diversity and composition as sampling was carried out during the warm and breeding period when the species commonly inhabiting or utilising the site were all present.

Table 4.7 shows the monthly numbers of fish caught in Belvedere and their percentage proportions in descending order. Figure 4.13 indicates the frequency of occurrences (% proportions) of the most abundant species in Greenwich from May 2000 to April 2001. The dominant species recorded in Belvedere over the five months sampling period was flounder (38.1%). Smelt was the second most abundant species (27.6%) followed by sea bass (13.3%), three-spined stickleback (8.2%), common goby (3.2%), Sand smelt (3.3%) and roach (1.6%). Like Greenwich, other species including sea bass, common goby, sand smelt and the three-spined stickleback were also present. Freshwater species were not abundant in this site (2.4% in total proportion).

Table 4.7 The monthly relative densities and % proportions of fish captured from Belvedere site in Zone 2 of the Thames Estuary from May 2000 to September 2000

species	May	Jun	Jul	Aug	Sept	Total	% prop
flounder	1002	55	40	17	32	1146	38.1
smelt	1	702	21	108	0	832	27.6
sea bass	0	0	180	180	40	400	13.3
3-s'stickleback	4	35	8	192	8	247	8.2
SSM	1	14	0	58	27	100	3.3
c' goby	0	0	0	72	24	96	3.2
roach	30	0	2	17	0	49	1.6
eel	12	9	5	2	1	29	1.0
plaice	1	2	6	9	5	23	0.8
dab	0	9	0	2	8	19	0.6
grey mullet	8	0	8	0	0	16	0.5
bleak	0	0	0	14	0	14	0.5
bream	3	3	3	3	0	12	0.4
dace	2	2	2	2	0	8	0.3
10-s'stickleback	0	0	0	0	8	8	0.3
barbel	5	0	0	0	0	5	0.2
15-s'stickleback	0	0	4	0	0	4	0.1
perch	0	0	0	2	0	2	0.1
Total	1069	831	279	678	153	3010	
% prop	35.5	27.6	9.3	22.5	5.1	100.0	

Figure 4.13 Frequency of occurrence fish species at Belvedere site May 2000 to September 2001



Grays

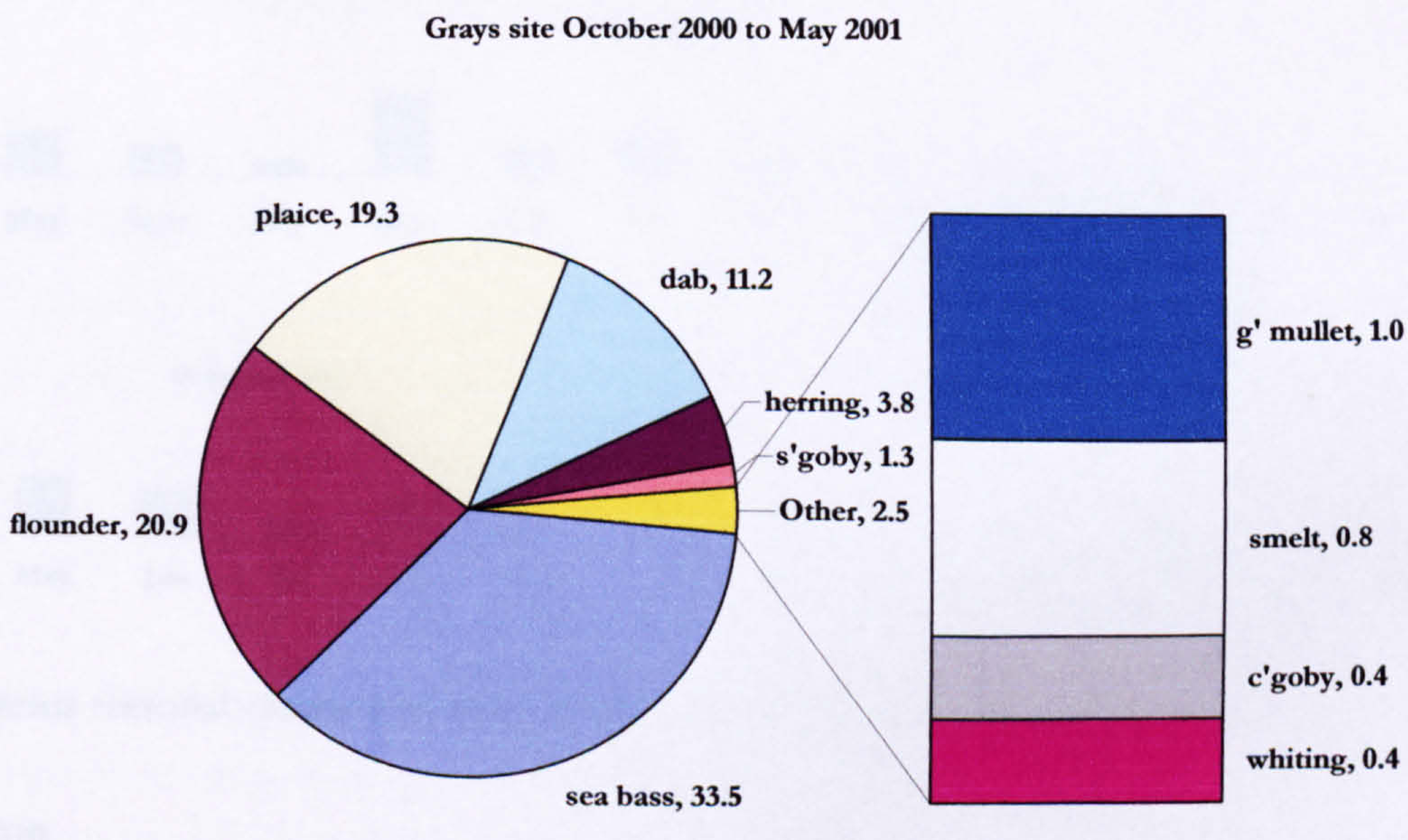
Table 4.8 shows the number and proportion of the fish species recorded at Grays in the monthly surveys. Figure 4 is a pie chart graph illustrating the percentage proportion of each species caught at Grays over the seven months sampling period. Sampling at Grays was predominantly undertaken in the cold period when breeding activities in the estuary for a majority of the species were not evident. October, the beginning of the sampling period at Grays is the period when mass migrations of juvenile fish in the estuary is usually observed (Wheeler, 1979; Araujo *et al* 1998 & 1999; Colclough *et al*, 1999 & 2000). For the rest of the sampling period i.e. from November to April population densities of most species in the estuary are generally low and this was the case for all other sites sampled in winter. Again because there is a lack of complete annual dataset for Grays quantitative comparisons with other sites are not realistic. However, because of the complete coverage of sampling of this site in the winter season and the existence of historical descriptions of species diversity in this locality, a qualitative comparison of species diversity with previous sites for the winter dataset was realistic. Eleven species were recorded at Grays from October 2000 to April 2001. All the species recoded were of marine origin as there were no fresh water species. The species captured in Grays within the cold sampling period were also described by Araujo *et al* (1998 & 1999) who used a large amount of data relating to the Grays locality. Generally, apart from differences imposed by differences in sampling intensities and sample sizes, species diversity in the

Grays locality generally compare with the diversity observed by Araujo *et al* (1998) for his nearby adjacent site of Thurrock. The most abundant species recorded at Grays were sea bass (35.5%), flounder (20.9%) place (19.3%), and dab (11.2%). Other minority species include Herring (3.8%) goby (1.3%), grey mullet (1%) and smelt (0.8%).

Table 4.8 The monthly relative densities and % proportions of fish captured from Grays site in Zone 2 of the Thames Estuary October 2000 to April 2001

species	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	% prop
sea bass	59	15	64	61	47	4	26	276	33.5
flounder	21	6	57	19	52	10	7	172	20.9
plaice	41	22	6	19	21	42	8	159	19.3
dab	12	34	8	4	8	8	18	92	11.2
herring	0	0	24	6	1	0	0	31	3.8
s'goby	0	0	0	0	6	5	0	11	1.3
g' mullet	0	8	0	0	0	0	0	8	1.0
smelt	0	0	0	0	4	0	3	7	0.8
c'goby	3	0	0	0	0	0	0	3	0.4
whiting	0	0	0	0	3	0	0	3	0.4
Total	136	85	159	109	142	69	62	762	
% prop	16.5	10.3	19.3	13.2	17.2	8.4	7.5		

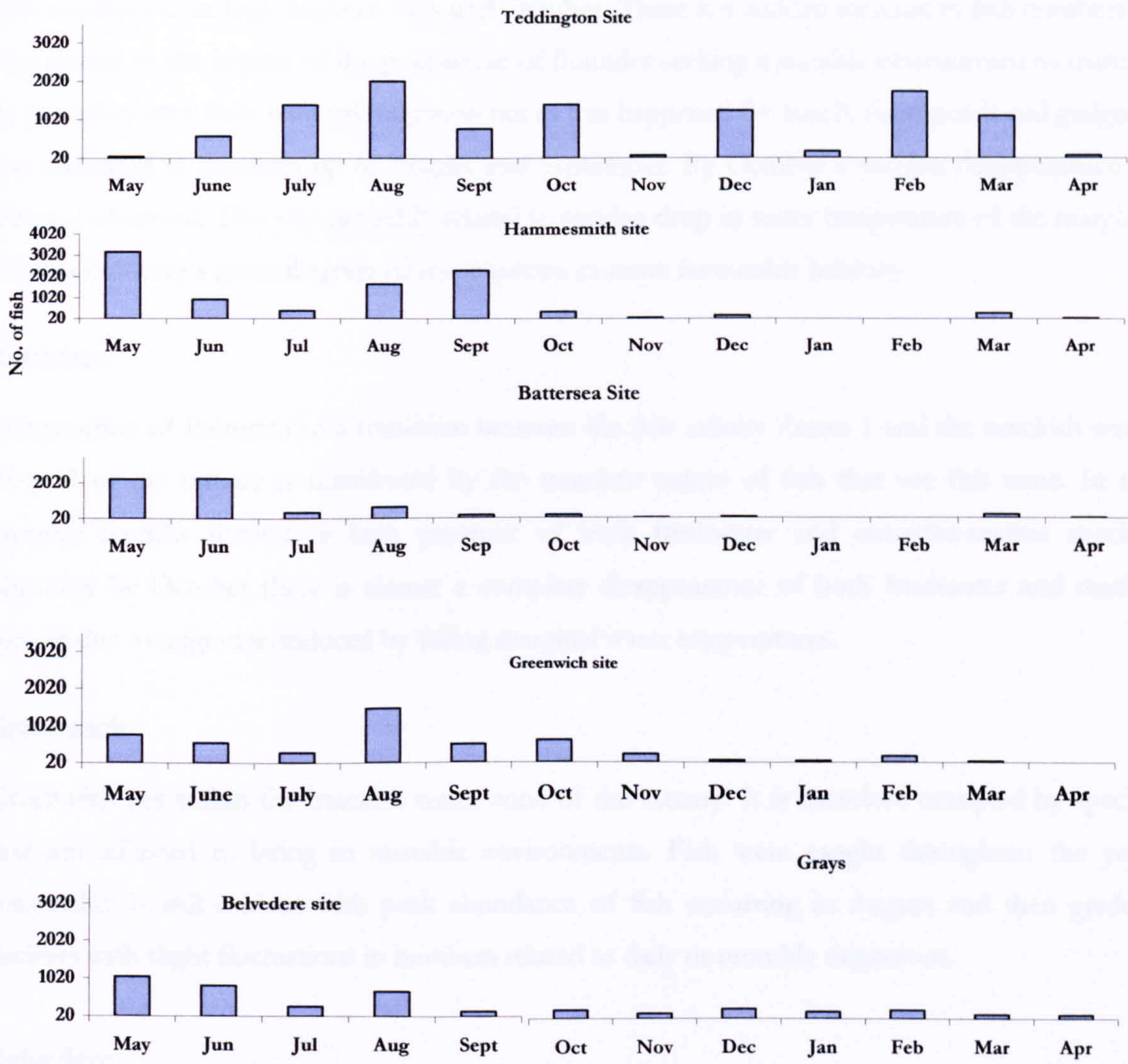
Figure 4.14 Frequencies of occurrence (% proportion) of the most abundant fish species at Grays October 2000 to April 2001



4.5.6 Monthly/Seasonal variation in fish numbers in the main river

Figure 4.15 shows the monthly variation in the number of fish captured from the main river sites.

Figure 4.15 Monthly variation of fish numbers at sites along the main river in 2000 and 2001



These patterns seasonal variation of fish numbers are described below:

Teddington

Teddington appears to have relatively stable numbers throughout the year. There was a steady increase in numbers from May to August. This increase was related to the spawning period of freshwater species during this time comprising roach, dace, perch and gudgeon. After this period the numbers remained high but there was a general oscillation was observed probably related to early spawning roach and local movements of roach and other species. However, the two peaks in the population densities (i.e. August and February) are related to the presence of large number of young of the year roach fry in those months. Young of the year roach were captured throughout the year in Teddington.

Hammersmith

Fish numbers were high between May and October. There is a sudden increase in fish numbers in May related to the ingress of the post larvae of flounder seeking a suitable environment to mature. By June they start their seaward migration but as this happened 0+ roach, dace, perch and gudgeon also increased in numbers up to August and September. By October a sudden disappearance of fish was observed. This was probably related to sudden drop in water temperature of the marginal habitats inducing a general egress of most species to more favourable habitats.

Battersea

The position of Battersea as a transition between the low salinity Zones 1 and the brackish water Zone 2 of the estuary is manifested by the transient nature of fish that use this zone. In the summer months there is a high presence of both freshwater and estuarine-marine species. However by October there is almost a complete disappearance of both freshwater and marine species due to migration induced by falling marginal water temperatures.

Greenwich

Greenwich lies within the brackish water zone of the estuary. It is therefore occupied by species that are adjusted to living in unstable environments. Fish were caught throughout the year. Seasonality is still evident with peak abundance of fish occurring in August and then gradual declines with slight fluctuations in numbers related to daily or monthly migrations.

Belvedere

Belvedere also lies within the brackish water zone of the estuary. This site was only sampled in the warm months of the year (May to September) and thus only shows the characteristics of warm season population dynamics namely high spring numbers due to the invasion of marine-dependent or transient (post larvae) species and spawning by estuarine species. There is an August peak due to the presence of the juveniles of all the species at the same time. Belvedere warm months' population densities have very similar characteristics with those of Greenwich. It is very doubtful whether the winter pattern of fish dispersion within Belvedere will be different from that of Greenwich. This doubt is supported by historical evidence (Colclough 1998 and 1999). This site is expected to have lower fish numbers in the cold months in order to have similar population density characteristics with other mid estuary sites as previously observed by Wheeler (1979) Chen (1992), Araujo *et al* 1999) Colclough (1996, Colclough *et al*, 1998 and 1999).

Grays

This site lies within the transition zone between the brackish water mid estuary and the high salinity zone 3. It was not sampled during the warm months as it was substituted for Belvedere. It was sampled in the cold months of the year from October 2001 to April 2002. October is observed to be the month when mass egress of marine species from the estuary occurs. Previous studies (Colclough *et al*, 1996 and 1998) have recorded greatly reduced population densities in the mid estuary in winter, especially for the young of the year.

4.5.7 Temporal and spatial abundance of common species in the main river

Table 4.9 and 4.10 show results for the two-factor and two-way ANOVA for fish abundance in comparable sites (Teddington, Hammersmith, Battersea and Greenwich), from May 2000 to April 2001

Table 4.9 Results of Two-factor ANOVA for monthly fish abundance in comparable sites (Teddington, Hammersmith, Battersea and Greenwich), from May 2000 to April 2001.

```
Analysis of Variance (species)
Source      DF        SS        MS        F        P
Factor      11  58228368   5293488     7.88    0.000
Error      132  88712067    672061
Total      143 146940435
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Species         Mean     StDev  -----+---------+---------+---------+-
roach         1336.5    1211.5                (---*----)
flounder       714.5    1747.5          (----*----)
dace          2051.0    1861.4                            (----*---)
gudgeon         26.7      64.8   (---*----)
bream           47.2     104.0   (---*----)
perch           23.3      53.8   (---*----)
3-spined        73.3     126.7   (----*---)
common g        40.0      90.4   (---*----)
sea bass       104.2     139.6   (----*----)
smelt           48.9     128.0   (---*----)
dab             11.3      10.0  (----*----)
plaice           6.3       6.0  (----*----)
                                   -----+---------+---------+---------+-
Pooled StDev =    819.8                 0      1000      2000      3000
```

```
Analysis of Variance (months)
Source      DF        SS        MS        F        P
Factor      11  14100654   1281878     1.27    0.246
Error      132 132839780   1006362
Total      143 146940435
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Month            Mean     StDev  ----------+---------+---------+------
May              1035      2382                   (--------*---------)
June              671      1197             (--------*---------)
July              333       564       (---------*--------)
Aug               798      1443               (--------*---------)
Sept              555      1196           (--------*---------)
Oct               360       690       (---------*---------)
Nov                46        51  (---------*--------)
Dec               236       498     (---------*--------)
Jan                33        65  (---------*--------)
Feb               178       379    (---------*---------)
Mar               229       517     (---------*--------)
Apr                10        15  (--------*---------)
                                   ----------+---------+---------+------
Pooled StDev =      1003                      0       600      1200
```

DF = degree of freedom; CIs = confidence intervals; StDev = standard deviations

Table 4.10 F-values of ANOVA for fish abundance in pooled results for Teddington, Hammersmith, Battersea and Greenwich from May 2000 to April 2001

ANOVA	*Source of Variation*					
species	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Roach	4036589	11	366962.7	1.5	0.2	2.8
Flounder	8398301	11	763481.9	4.5	0.0	2.8
Dace	153573.7	11	13961.25	0.9	0.6	2.8
Gudgeons	11556.17	11	1050.561	1.0	0.5	2.8
bream	29732.92	11	2702.992	1.0	0.4	2.8
Perch	7973.667	11	724.8788	1.0	0.5	2.8
3-spine stickleback	44125.06	11	4011.369	2.8	0.0	2.8
common goby	22454	11	2041.273	1.5	0.2	2.8
sea bass	53598.42	11	4872.583	1.4	0.2	2.8
smelt	45025.23	11	4093.203	1.0	0.5	2.8
dab	275.1667	11	25.01515	1.0	0.4	2.8
Plaice	99.5625	11	9.051136	1.8	0.1	2.8

Level of significance P = 0.05

SS = sum of squares; df = degree of freedom; MS = means of squares

Two-way ANOVA shows that except for flounder the mean abundance of most abundant species differed significantly between months, and that most interactions between months and species show significant F-values (Table 4.10). High values and significances are shown for monthly comparisons implying that for all species there is at least one monthly mean that differs highly significantly from the other months. Since ANOVA shows that the abundances of most species are influenced to a greater degree by month, monthly abundance has been investigated for each site over the 4 comparable main river sites. With all monthly species data pooled for Teddington, Hammersmith, Battersea and Greenwich sites from May 2000 to April 2001 marked variations in abundance were found between monthly means for most of the top 12 numerous species. Some species like roach, gudgeon, goby, smelt and three-spined stickleback show peak abundances between July and August. Some species like dab, bream and plaice show the opposite pattern (Figure 4.16). An assessment for each species is given below: Lack of sampling during winter months in Belvedere and summer months in Grays should be borne in mind when interpreting seasonal variations, especially because only one brackish water site (Greenwich) is included in the analysis and abundances of some species could have been missed. However, over a 12 month period the results are worthwhile for the robustness and wide coverage of the estuary.

Figures 4.16 to 4.21 (pages - 141 - to - 146 -) show the monthly values for roach, flounder, dace, perch, three-spined stickleback, common goby, sea bass, smelt, dab and plaice. These species are found in substantial numbers in both Zones 1 and 2 but exhibits different abundances at different sites and different seasons

Figure 4.16 Monthly values for abundances of the 12 most numerous fish species in all sites along the main river

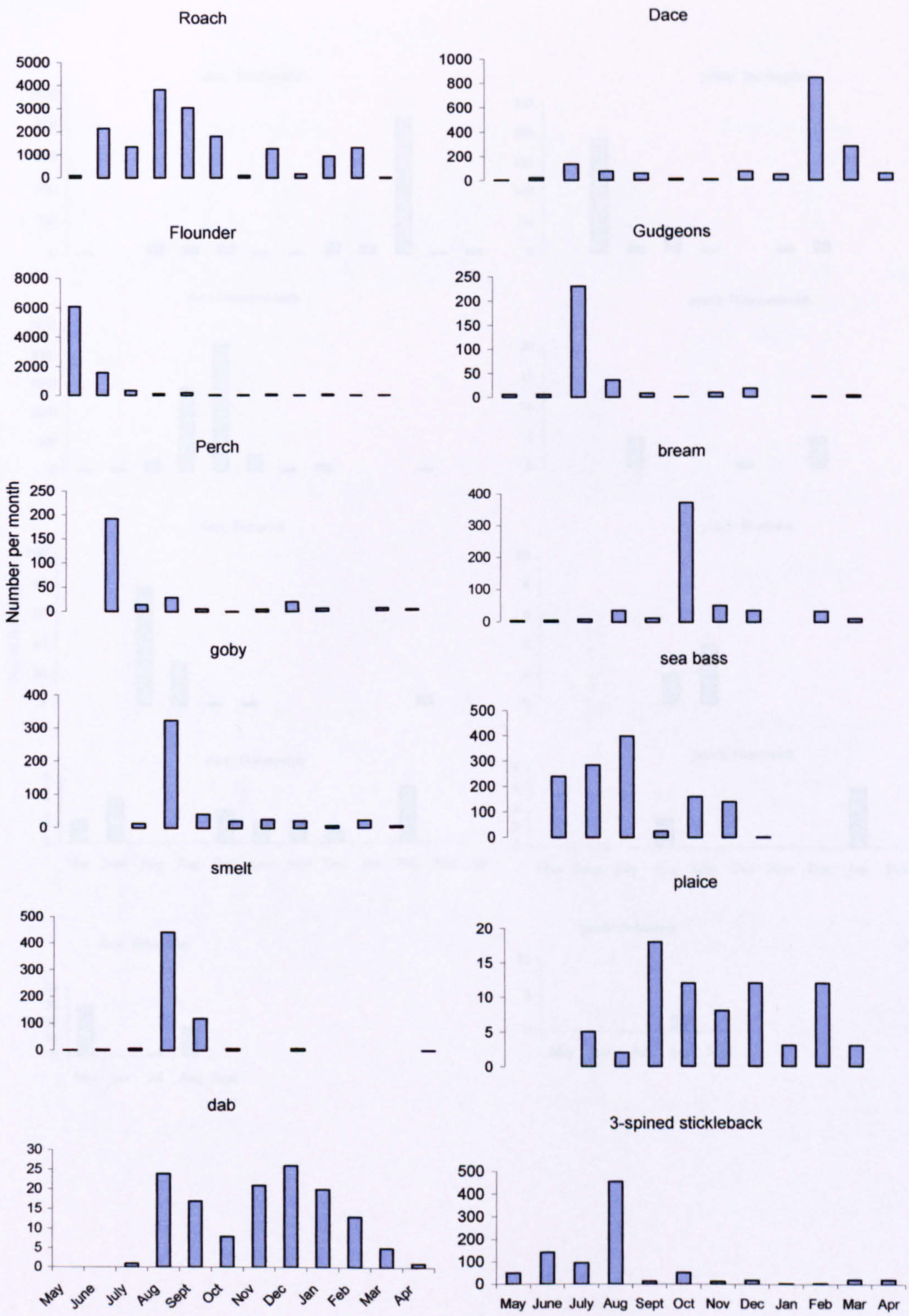


Figure 4.17 Monthly values for dace and perch abundances at sites along the main river

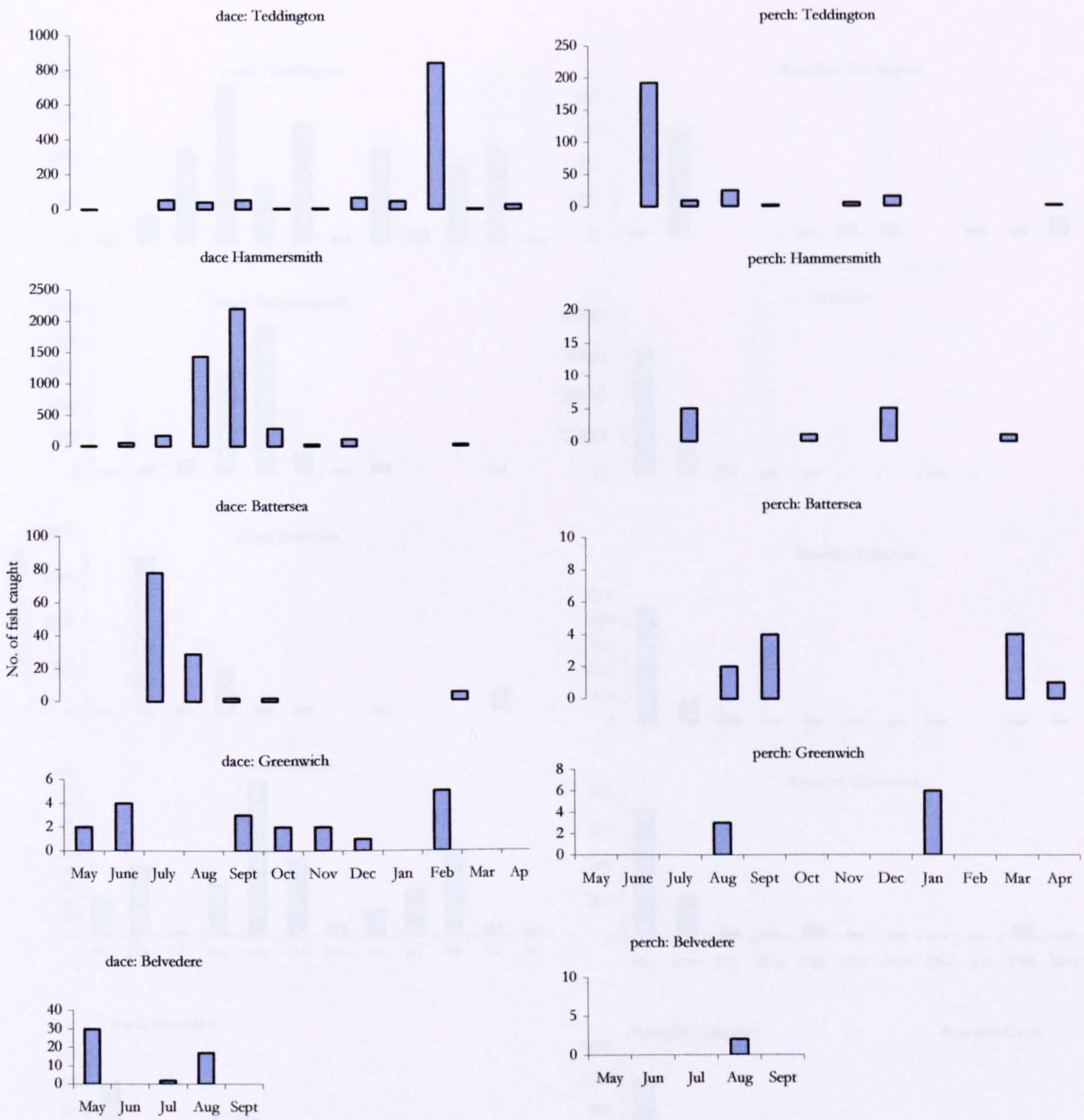


Figure 4.18 Monthly values for roach and flounder abundances at sites along the main river

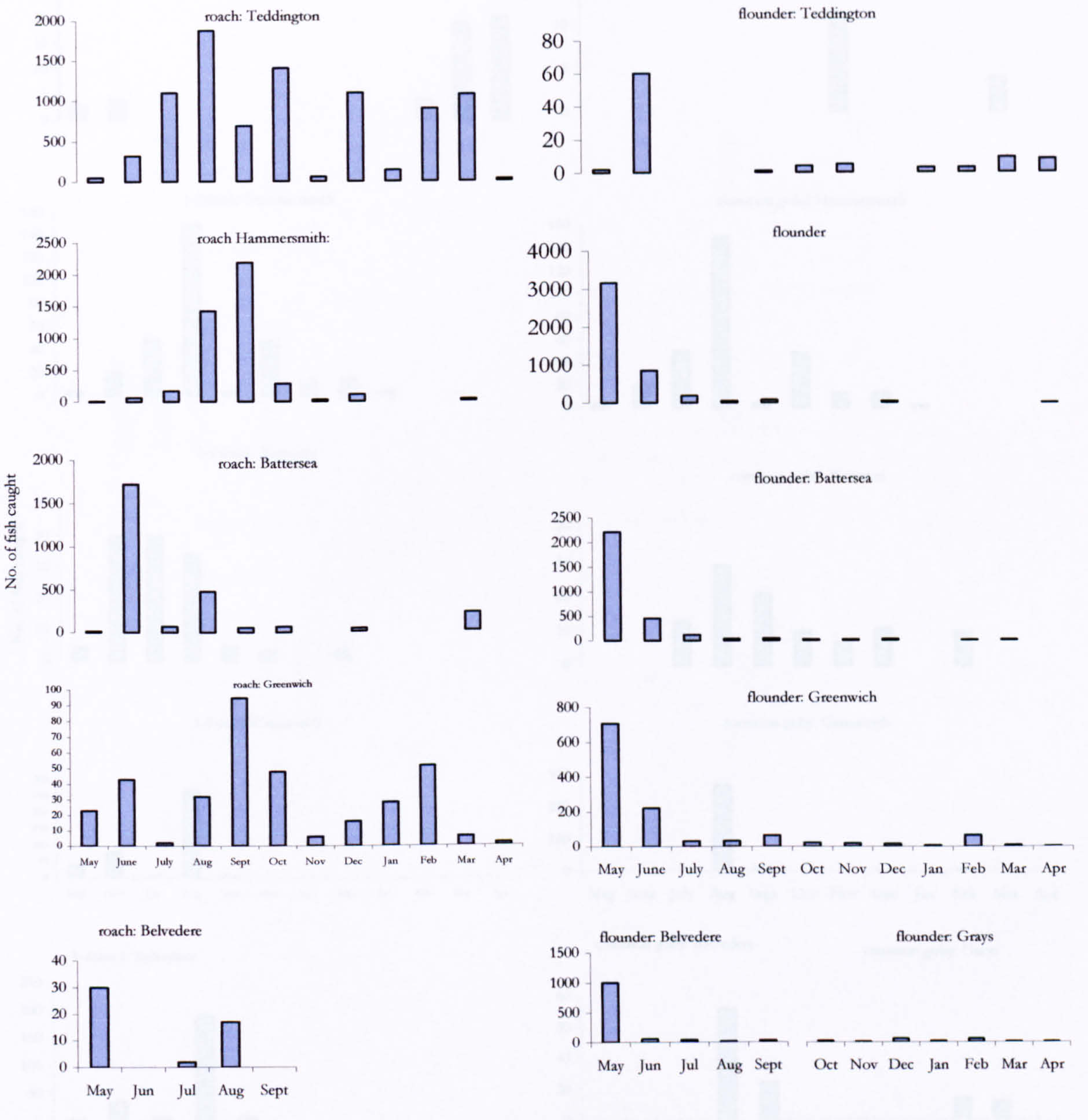


Figure 4.19 Monthly values for three-spined stickleback and common goby abundances at sites along the main river

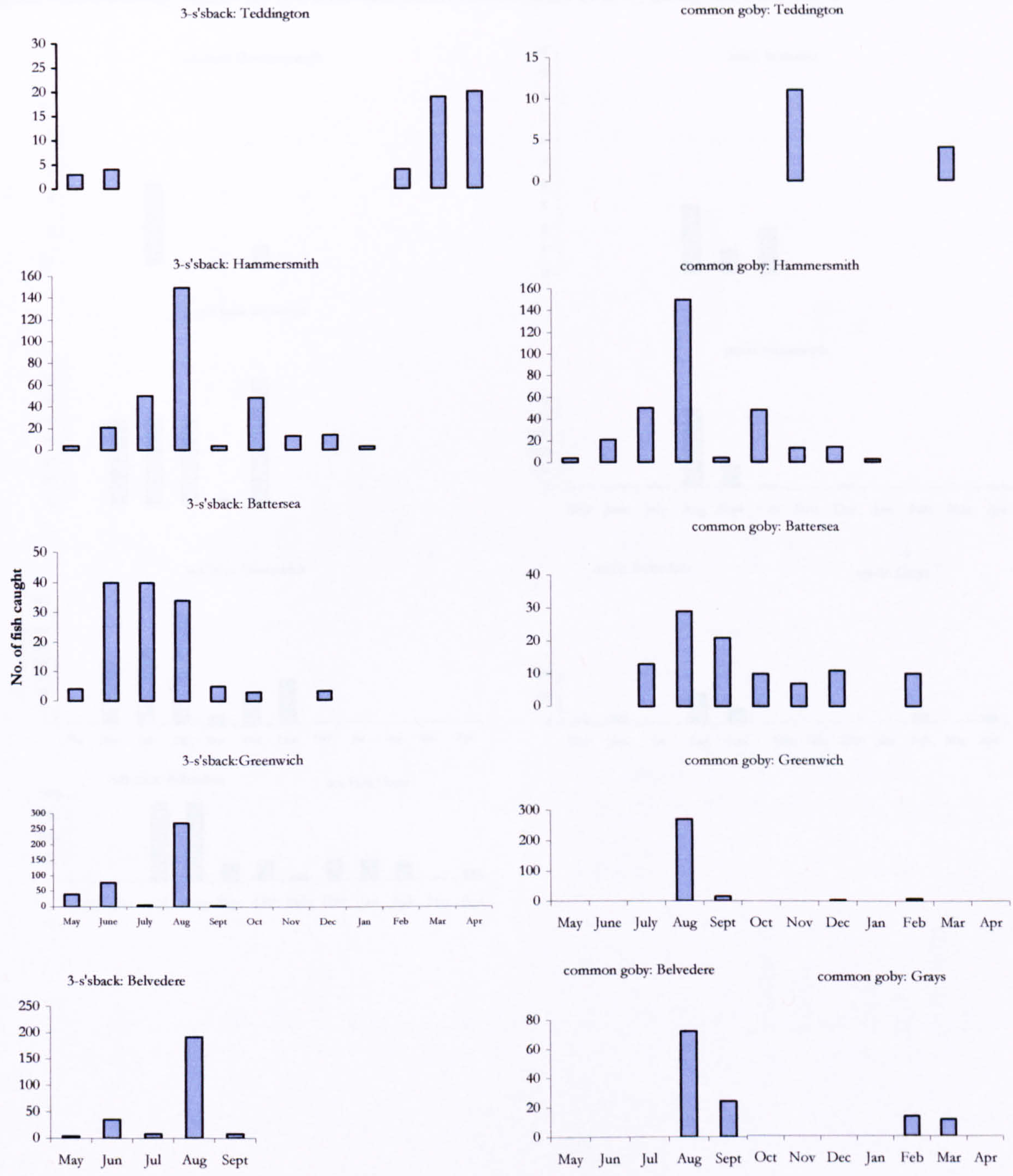


Figure 4.20 Monthly values for sea bass and smelt abundances at sites along the main river

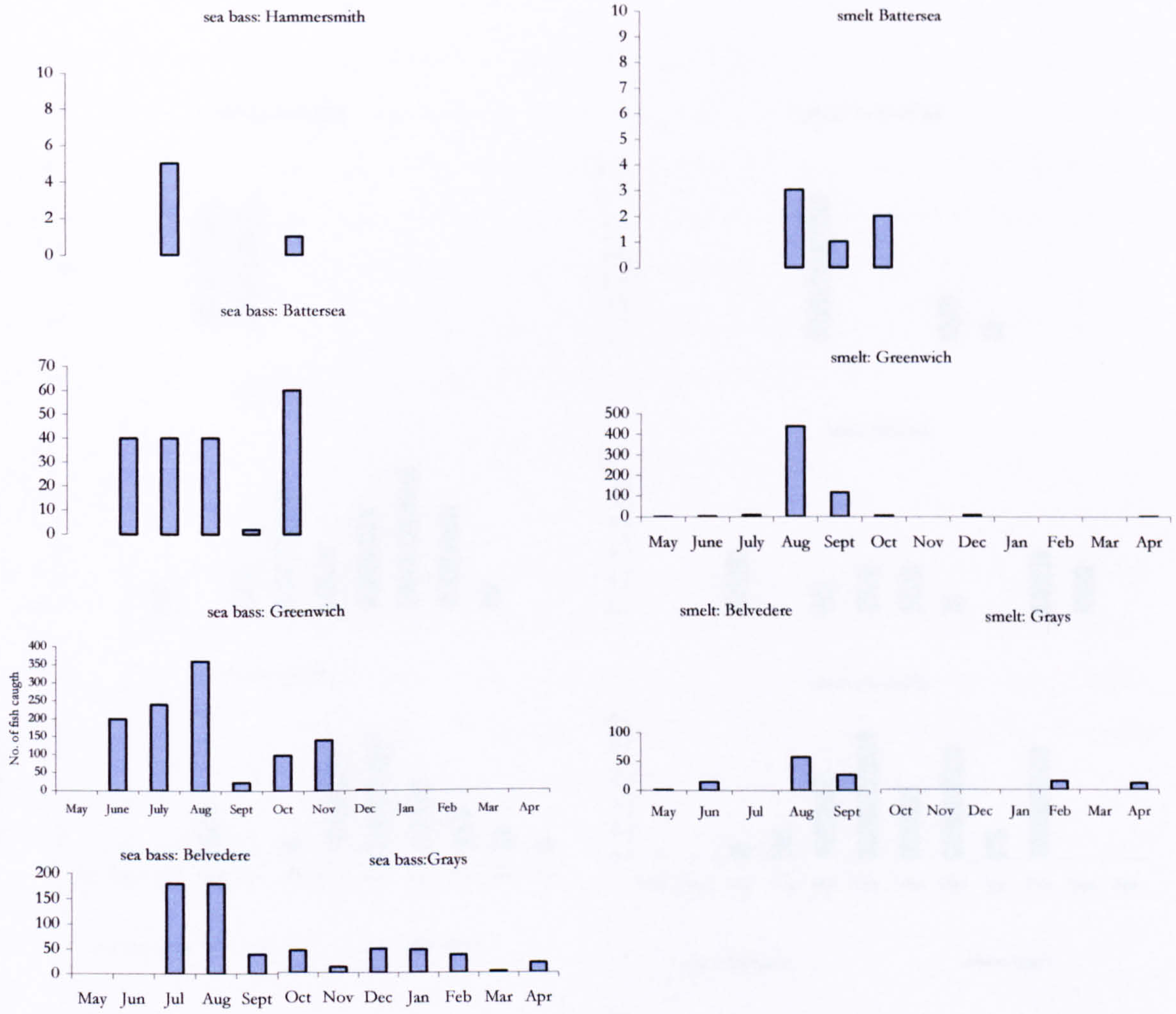
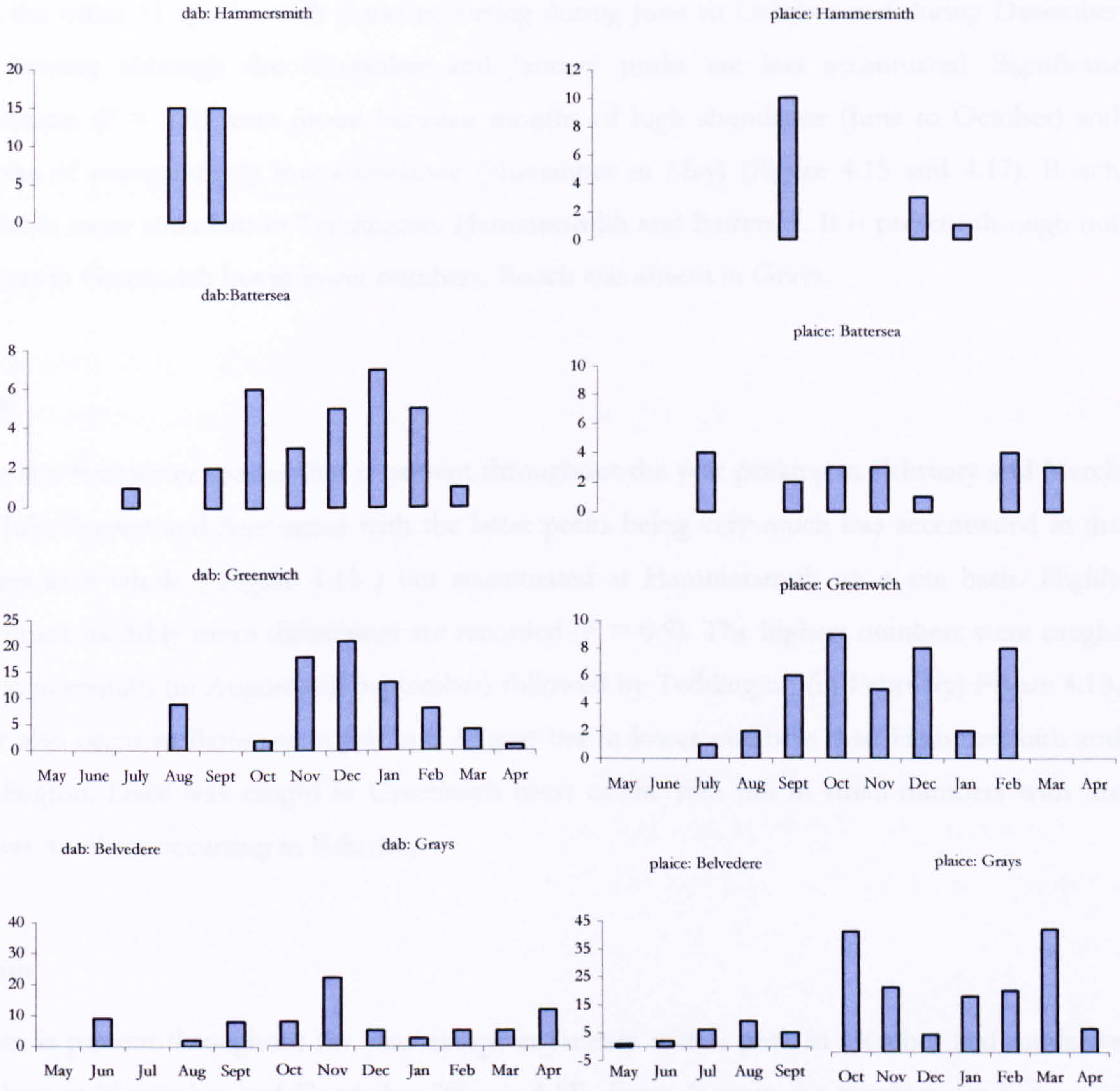


Figure 4.21 Monthly values for the dab and plaice abundances at sites along the main river



Freshwater species: all sites

Freshwater species are those which originate from the upper region of the river Thames and its associated tributaries.

Roach

Roach is present throughout the year. This species experiences less seasonality in its abundance than the other 11 species with peaks occurring during June to October and during December and January although the December and January peaks are less accentuated. Significant differences ($F = 1.5$) were found between months of high abundance (June to October) and months of comparatively low abundance (November to May) (Figure 4.15 and 4.17). Roach species is more abundant in Teddington, Hammersmith and Battersea. It is present through out the year in Greenwich but in lower numbers. Roach was absent in Grays.

Dace

Dace is a freshwater species that is present throughout the year peaking in February and March and July, August and September with the latter peaks being very much less accentuated in the estuary as a whole (Figure 4.15) but accentuated at Hammersmith on a site basis. Highly significant monthly mean differences are recorded ($F = 0.9$). The highest numbers were caught in Hammersmith (in August and September) followed by Teddington (in February) Figure 4.18. They also occur in Battersea in July and August but in lower numbers than Hammersmith and Teddington. Dace was caught in Greenwich most of the year but in small numbers with the highest numbers occurring in February.

Bream

Bream is present throughout the year except in January with a peak in October and moderate numbers in November and December (Figure 4.15). From January the numbers are low up to September. Highly significant monthly means are recorded ($F = 1.0$).

Gudgeon

Gudgeon does not display very high monthly numbers but is present throughout the year except January with peak numbers occurring in July. From August the numbers decline sharply, highly significant monthly means are recorded ($F = 1.0$) between the summer peaks and the low numbers of the rest of the year.

Perch

Perch is present in low numbers most of the year with an accentuated peak in June. Sharp drops are observed in July and August followed by accentuated drops September to May Figure 4.15). The high numbers in June are associated with spawning of the species which takes place in June. There are highly significant differences between monthly means (F = 1.0). On site basis the highest numbers were caught in Teddington in June (Figure 4.18).

Marine and marine-estuarine dependent species: all sites

Flounder

Unlike other species, flounder is more abundant in summer showing a clearly defined peak in May. Abundance decreases from June, July onward reaching the lowest level in February (Figures 4.15 and 4.17). Highly significant differences (F = 4.5) are found between monthly means with accentuated separation between August to April. The number of flounder caught decreased downstream.

Common goby

Highly significant differences (F = 1.5) are found between months. Peaks occur in August. This is related to their spawning period being July and August, and troughs occur between September and June. Common goby are captured in 9 of the 12 months of the year. They seem to be undetectable throughout May and June.

Sea bass

Highly seasonal, this fish occurs July to January, with a peak in September then becoming virtually absent between February and May (Figure 4.16). Highly significant differences (F = 1.4) are found between monthly comparisons (Table 4.10).

Plaice

This species occurs most of the year round but in low numbers with the highest numbers occurring from September to December (Figure 4.21). Highly significant differences were found between monthly means, especially January to August.

Dab

This species is present between July and April, peaking in August and December and becoming virtually absent in May and June (Figure 4.21). Highly significant differences were found between monthly means (F = 1.0)

Smelt

Smelt is present most of the year with peaks occurring in August and September with accentuated difference from October to July. The species is abundant in the mid estuary sites of Greenwich and Belvedere (Figure 4.20) in August and September. Highly significant differences were found between monthly means (F = 1.0). Smelt was not caught in Teddington and Hammersmith.

Three-spined stickleback

This species was captured throughout the year except in January and February, peaking in abundance between May and August. From September there is a sharp decrease in abundances with the lowest numbers occurring between September and April. Highly significant differences (F = 2.8) are found between monthly means (Table 4.10).

4.5.8 Age Composition analysis: 0+ individuals

Table 4.11 shows the % proportion of 0+ individuals of the fish species captured in sites along the main river. The low salinity areas of the upper estuary (Zone 1) exhibit high abundances for post larval individuals of the marine species flounder and the fresh water individuals of the freshwater species roach and dace. As a primary nursery area Zone 1 is characterised by the presence of a large number of post larval and 0+ fish. In addition to the young of the year of flounder being abundant, the brackish water area of the mid estuary (Zone 2) also exhibits high 0+ abundance of other marine and marine-estuarine species such as three-spined stickleback, sea bass, common goby and smelt.

At Teddington, the freshwater species roach (82.8%), dace (12.3%) and perch (2.9%) make up the majority of 0+ fish captured at the Teddington site. Hammersmith is characterised by high abundances of 0+ individuals of flounder (54.6%), roach (41.3%) and three-spined stickleback (3.4%). At Battersea, the 0+ individuals of flounder (63.5%) and roach (31.2%) form the majority of 0+ individuals but other species comprising three-spined stickleback (1.5%), sea bass (1.5%) and dace (1.2%) are present. Greenwich shows a more even presence of 0+ individuals of marine and marine-estuarine species comprising flounder (32.2%), sea bass (21.2%), smelt (16.0%), three-spined stickleback (14.9%), common goby (10.2%) and grey mullet (1.8%). 0+ dace and perch are absent from Greenwich and 0+ roach comprised only 1.5%. Belvedere shows a similar pattern to Greenwich for the abundance of 0+ fish species with marine and marine-estuarine dependent species forming a majority of 0+ fish community. Flounder (44.6%), smelt (29.1%), sea bass (14.5%) and three-spined stickleback (9.1%) form the majority of 0+ fish of the sites 0+ fish population. Like Greenwich, Belvedere does not contain a high % of 0+ individuals of any freshwater species. It is very important to reiterate again that Grays and Belvedere cannot be quantitatively compared with other sites in terms of relative densities of individuals due to the incomplete annual datasets for these two sites. Grays has no 0+ individuals of any species. The reason for this may be due partly to the salinity levels (Grays being geographically close to Zone 3) and the fact that sampling at this site was carried out during the cold months when fish breeding is not evident in Zone 2 of the estuary.

Table 4.11 % proportion of 0+ fish species captured by a 4mm knotless seine net from sites in Zones 1 and 2 of the Thames Estuary from May 2000 to April 2001.

Site	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays
roach	82.8	41.3	31.2	1.5	0.9	0.0
flounder	1.0	54.6	63.5	32.2	44.6	0.0
3-s'stickleback	0.6	3.4	1.5	14.9	9.1	0.0
dace	12.3	0.1	1.2	0.0	0.0	0.0
sea bass	0.0	0.1	1.5	21.2	14.5	0.0
bream	0.0	0.0	0.1	0.4	0.0	0.0
cmmon goby	0.1	0.2	0.8	10.2	1.2	0.0
smelt	0.0	0.0	0.0	16.0	29.1	0.0
sand smelt	0.0	0.0	0.1	0.4	0.0	0.0
perch	2.9	0.0	0.0	0.0	0.0	0.0
eel	0.0	0.0	0.0	0.1	0.0	0.0
grey mullet	0.0	0.2	0.0	1.8	0.6	0.0
bleak	0.3	0.1	0.0	0.0	0.0	0.0

4.5.9 Age Composition analysis: 1+ individuals

Table 4.12 shows the relative % composition of 1+ individuals captured at sites along the main river as with 0+. Data for age classes abundance are presented in Appendix 4 (Tables 1-12). The % of 1+ individuals present at is dependent on the species, the distance of the site from the sea and the season. However 1+ individuals for a majority of the species tend to disperse to a wider range of habitats. At Teddington, 1+ roach constitute 76.5% of the 1+ fish population of the site followed by dace (8.3%) and minnow (8.0%). Chub, perch and bream constitute 2.2%, 1.4% and 1.1% respectively.

Table 4.12 % proportion of 1+ fish species captured by a 4mm knotless seine net from sites along the main river from May 2000 to April 2001

Site	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays
roach	76.5	70.6	32.0	16.5	5.0	0.0
flounder	0.8	2.8	17.6	15.5	6.7	22.4
3-s'stickleback	0.2	2.0	2.2	0.2	3.8	0.8
dace	8.3	18.0	5.0	1.0	1.5	0.0
sea bass	0.0	0.1	10.4	14.5	7.2	35.9
bream	1.1	0.9	4.1	23.1	2.3	0.0
common goby	0.3	2.6	5.8	0.6	12.8	0.4
smelt	0.0	0.0	0.9	9.4	25.7	0.9
sand smelt	0.0	0.5	11.1	9.9	13.9	0.0
perch	1.4	0.6	1.9	0.5	0.4	0.0
chub	2.2	0.0	8.7	0.0	0.0	0.0
eel	0.0	0.2	0.2	0.1	3.2	0.0
bleak	0.0	0.5	0.0	2.2	4.4	0.0
plaice	0.0	0.5	0.0	2.2	4.4	20.7
dab	0.0	0.8	0.0	4.0	3.6	12.0
gudgeon	0.5	0.1	0.0	0.0	2.3	0.0
minnow	8.0	0.1	0.0	0.0	0.0	0.0
whiting	0.0	0.0	0.0	0.0	0.0	4.0

At Hammersmith, 1+ roach constitute 70.6% of the 1+ fish population of the site followed by dace 18.0%, the marine and estuarine dependent species comprising flounder (2.8%), common goby (2.6%) and three spined sticklebacks (2.0%). It is important to note that although flounder constitute 45.7% of the total annual catch at Hammersmith, 1+ flounder only constitute 2.8% of the total 1+ fish population caught from the site. Battersea shows a more even composition of 1+ fish and also reflects the transitional nature of the site by exhibiting high percentage compositions for 1+ estuarine and marine-estuarine dependent species. The freshwater species roach represents 32% of the of 1+ fish population in Battersea site and is followed by flounder (17.6%), sand smelt (11.1%), sea bass (10.4%), chub (8.7%), common goby (5.8%), dace (5.0%), bream (4.1%), three-spined stickleback (2.2%) and perch (1.9%). These results show that apart from flounder the proportion of other 1+ marine and marine-estuarine dependent fish are higher in Battersea than their 0+'s (see Table 4.11 and 4.12). Greenwich, located within the brackish water zone, contains a high percentage proportion of 1+ roach and bream which is a very interesting observation given the fact that Greenwich lies within a higher strength salinity zone than Battersea, Hammersmith and Teddington. Bream constitute 23.1% of the total 1+ fish at Greenwich site followed by roach (16.5%) also a freshwater species. The 1+ cohort of true estuarine species comprise flounder (15.5%), sea bass (14.5%), sand smelt (9.9%), smelt (9.4%), place (2.2%) and dab (2.2). In Belvedere throughout the five months period of sampling, smelt (25.7%), sand smelt (13.9%), common goby (12.8%), sea bass (7.2%) and flounder (6.7%) are the most abundant 1+ fish. The 1+ year classes of dab (4.2%), place (4.2%) are also well represented. Five species form the main components of the 1+ fish populations in Grays namely: sea bass (35.9%), flounder (22.4%), plaice (20.7%), and dab (12.0%) and whiting (4%).

4.5.10 Overview of temporal and spatial distribution of 0+ and 1+ fish

Apart from roach, offshore spawned fishes dominate the the fish populations of the reaches of the upper and mid Thames Estuary in summer Table 4.11 and 4.12. Their juveniles reside for several months in shallow, low and mid salinity brackish water gravel and soft-bottom estuarine reaches called Primary Nursery Areas (Boesch and Turner, 1984; McIvor and Odum, 1988; Miltner *et al.*, 1995). Despite similarities in many nursery characteristics, there is, between and within species, variability in the occupation of these habitats. Whether all occupied habitats are equally valuable to individuals of the same species or whether most recruiting juveniles end up in the best habitats is not known. If nursery quality varies, then factors controlling variation in pre-settlement fish distribution are important to year-class success.

The general estuarine distributions of two dominant estuarine summer spawned fishes, sea bass and smelt, exhibit consistent patterns throughout their ranges. Juvenile sea bass routinely concentrate in brackish zones; a pattern that suggests that the mid estuary reaches are most valuable to this species. 0+ sea bass and smelt occurred in the greatest abundance in the brackish water sites of Greenwich and Belvedere but not in Teddington, Hammersmith or Grays. The 1+ of these species are distributed in an opposite fashon to the 0+. Flounder, however, are more ubiquitously and variably distributed through the shallow Primary Nursery Areas, perhaps indicating less dependence on a particular estuarine region because of the species ability to survive in variable salinities. Despite these generalities, all the three species can be present in large numbers in almost any estuarine salinity range. In general, juveniles of the three species seem to avoid (or are unsuccessful in) more open water areas of estuaries and high salinity areas during the early part of the nursery period.

Tables 4.13 and 4.14 represent the monthly % proportions of 0+ and 1+ fish captured from sites in Zones 1 and 2 of the Thames Estuary from May 2000 to April 2001. The greatest abundance of the 0+ year class occurs in the months of May, June, July, August and September for Hammersmith, Battersea, Greenwich and Belvedere. There is a delay in the emergence of 0+ fish in Teddington. The first wave of 0+ fish in Teddington does not occur until June.

Table 4.13 Monthly % proportions of 0+ fish captured by a 4mm knotless seine net from sites in Zones 1 and 2 of the Thames Estuary from May 2000 to April 2001

			Site			
Month	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays
May	0.27	40.29	28.03	26.70	69.26	NA
June	8.37	11.11	28.61	10.52	3.61	NA
July	15.23	4.49	4.47	10.80	9.15	NA
August	28.57	23.34	7.91	47.67	15.73	NA
September	8.58	17.33	1.10	2.73	2.25	NA
October	3.22	2.45	0.58	1.15	NA	0
November	0.62	0.56	0.18	0.00	NA	0
December	5.39	0.37	0.06	0.07	NA	0
January	0.70	0.01	0.00	0.22	NA	0
February	12.36	0.01	0.01	0.14	NA	0
March	16.38	0.04	1.58	0.00	NA	0
April	0.30	0.00	27.47	0.00	NA	0

NA = not available

Table 4.14 Frequency of occurrences of 1+ fish captured by a 4mm knotless seine net from sites in Zones 1 and 2 of the Thames Estuary from May 2000 to April 2001.

			Site			
Month	Teddington	Hammersmith	Battersea	Greenwich	Belvedere	Grays
May	1.36	2.23	2.74	1.86	8.76	NA
June	0.93	3.75	0.00	3.41	6.10	NA
July	10.34	2.99	2.05	1.07	10.48	NA
August	3.16	7.31	8.39	4.79	55.43	NA
September	2.66	47.34	18.49	23.07	19.24	NA
October	30.08	8.17	28.94	33.78	NA	17.71
November	1.28	1.42	4.11	13.11	NA	11.07
December	20.21	7.61	7.36	4.85	NA	20.70
January	3.64	0.46	0.00	3.30	NA	14.19
February	23.47	0.30	2.05	8.31	NA	18.49
March	1.03	15.17	17.81	2.18	NA	9.77
April	1.83	3.25	8.05	0.27	NA	8.07

NA = not available

The general distribution of 1+ fish throughout the year does not seem to take a specific pattern. The general populations within and between sites seem to oscillate in response to daily and monthly upstream and downstream migrations (Table 4.14). However the general monthly 1+ populations are highest in the months of August, September and October and lowest in the months of May and June. The winter months of November, December, January and March have intermediate 1+ fish percentage proportions.

1+ Dab and place are important species in the mid Thames Estuary but there are no 0+ cohorts there, meaning that these two species do not spawn in the mid estuary. 1+ Dab populations show strengths in Greenwich and Belvedere and those of plaice in Greenwich, Belvedere and Grays.

Analysis of the age composition of the fish caught (Tables 4.11, 4.12, and 4.13) shows that it is primarily the 0+ fish which are lost from the river sites during the cold months. The overall ratio of 0+:1+ fish in summer was 7:1 whilst in winter this drops to 3:5. The ratio would have dropped to 1:4 if it were not for the high numbers of 0+ roach and dace captured at Teddington in winter. 24,580 0+ fish were captured in summer. In the same season a total of 3,631 1+ fish were captured

For individual species the annual spring increase in 0+ numbers may be attributed to a number of factors. For example roach breed at Teddington and gradually migrate downstream. Dace probably breed as far down as Hammersmith and again migrate downstream over the spring to summer period. Conversely the Flounder breeds at sea and the post-larvae voyage upstream reaching Hammersmith in April/May. Sea bass fry enter the middle estuary from April-May depending on water temperatures and move upstream as far as Hammersmith. Smelt spawn within the estuary at Greenwich and Belvedere in May and June and move up to Battersea in significant numbers and a few reach Hammersmith.

The loss of the 0+ fish of all species tended to begin in October (Table 4.13) and most of the 0+ fish had disappeared by November. There was no evidence of increasing 0+ fish numbers in the Creeks and Docks during the winter months. In fact, their numbers also decreased sharply in the majority of the additional habitats studied as will be addressed later.

Examination of 1+ numbers showed no marked summer increase and numbers did not fall considerably in winter. It thus appeared that the 1+ fish numbers in the estuary were more stable seasonally suggesting that they survive in the Estuary.

The overall conclusion from these observations was that apart from Teddington, the margin of the estuary becomes a hostile environment for 0+ fish at the onset of winter and that huge losses (or perhaps migration) occur at this time of year. There is no evidence at the present time that the fish are to be found in refugia within the Thames during winter months.

4.5.11 Results - Additional Habitat Surveys

The additional habitats surveyed include the Dartford Creek, the East India and Queen Victoria Docks. Results for these surveys are presented in the following sections.

Species Captured in the additional habitats

Species captured in the Dartford Creek, East India and Queen Victoria Basins are shown in Table 4.15

Table 4.15 Fish species recorded in the additional habits

Common name	Latin name	Dartford Creek	Queen Victoria Dock	East India Dock
roach	*Rutilus rutilus*	X	X	X
flounder	*Platichthys flesus*	X	X	X
3-s,stickleback	*Gasterosteus aculeatus*	X	X	X
dace	*Leuciscus leuciscus*	X	X	X
sea bass	*Dicentrarchus labrax*	X	X	X
bream	*Abramis brama*	X		X
common goby	*Pomatoschistus microps*	X	X	X
smelt	*Osmerus eperlanus*	X	X	X
sand smelt	*Atherina presbyter*		X	X
perch	*Perca fluviatilis*	X	X	X
chub	*Leuciscus cephalus*	X	X	X
sand goby	*Pomatoschistus minutus*		X	X
10-s'stickleback	*Pungitius pungitius*	X		X
eel	*Anguilla anguilla*	X	X	X
grey mullet	*Liza ramada*	X		X
bleak	*Alburnus alburnus*			X
dab	*Limanda limanda*			X
plaice	*Pleuronectes platessa*			X
gudgeon	*Gobio gobio*		X	X
herring	*Clupea harengus*	X		
sprat	*Sprattus sprattus*	X		
roach x bream	*Roach & bream hybrid*			X
	Total	**15**	**12**	**20**

estuarine-marine dependent species
freshwater species

Dartford Creek

Dartford Creek Survey was conducted by the Environment Agency. Fifteen species of fish were captured in the creek system. Thirteen species were recorded in the main creek, 10 were recorded in the Darent Arm and 14 in the Crayford Arm (see Table 4.16). Flounder, common goby and eels were found everywhere in the creek system. Sprat, sea bass, herring, chub, three-spined stickles and bream were recorded in the main creek only suggesting that these species were visitors in the creek from the main river. Roach and dace were captured only in the Darent and Crayford Arms but not in the main creek suggesting that these species breed in the low salinity parts of the Darent and Crayford Arms salinity within the main arm of the creek at mid tide high water was too high. Mullet were caught in the main creek and Darent Arm. Perch and ten-spined stickleback were present only in the Crayford Arm. This distribution of species in the creek complex was probably determined by migration, breeding and salinity gradients.

Table 4.16 shows the species densities and relative % proportions of fish in the Dartford Creek captured with a trawl net by the Environment Agency in June, July, August and September 2001. Figures 4.22, 4.23 and 4.24 show the frequency of occurrences (% proportion) of the major species captured from the Main Creek, Darent and Crayford Arms respectively.

Table 4.16 Relative species densities and relative % proprtions of fish in the Dartford Creek captured with a trawl net by the Environment Agency in June, July, August and September 2001

	Main Creek		Darent Arm		Crayford Arm	
Species	Creek	%prop	Total	% prop	Total	% prop
smelt	734	44.9	6	0.7	56	1.8
flounder	556	34.0	564	62.6	1784	57.3
c'goby	178	10.9	100	11.1	658	21.1
sprat	91	5.6	0	0.0	95	3.0
Grey mullet	28	1.7	0	0.0	9	0.3
eel	20	1.2	18	2.0	58	1.9
herring	8	0.5	0	0.0	0	0.0
roach	5	0.3	176	19.5	366	11.7
sea bass	5	0.3	1	0.1	8	0.3
dace	3	0.2	20	2.2	44	1.4
3-s'stickleback	2	0.1	8	0.9	18	0.6
10-s'stickleback	0	0.0	0	0.0	1	0.0
bream	2	0.1	0	0.0	2	0.1
chub	1	0.1	6	0.7	13	0.4
perch	0	0.0	2	0.2	4	0.1
Total	1633	100.0	901	100.0	3116	100.0

Figure 4.22 Frequency of occurrences (% proportion) of the major species captured from the Main Creek of the Dartford Creek system sampled with a trawl net by the Environment Agency

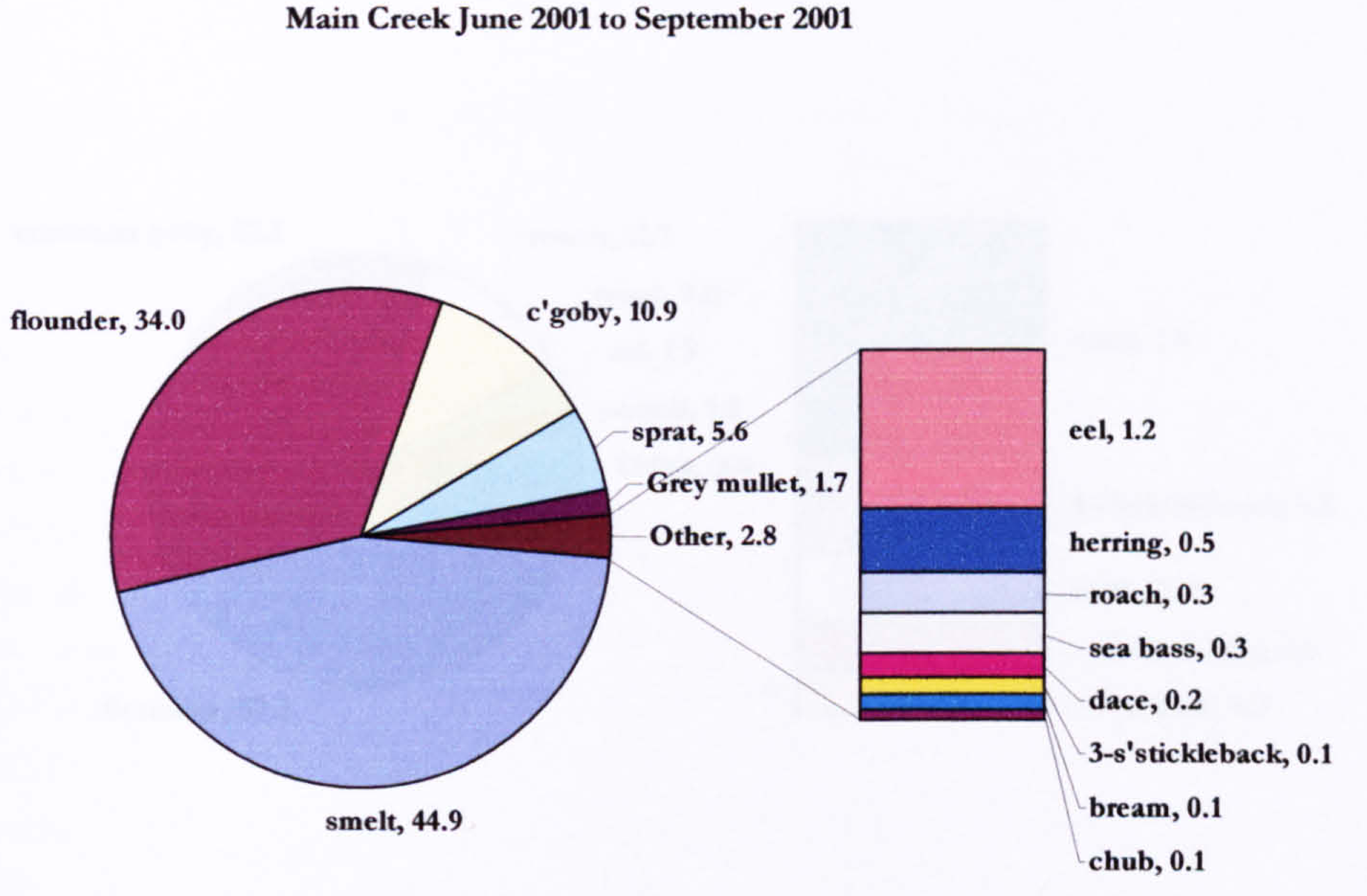


Figure 4.23 Frequency of occurrence (% proportion) of the most abundant species captured from the Darent Arm of the Dartford Creek system by the Environment Agency

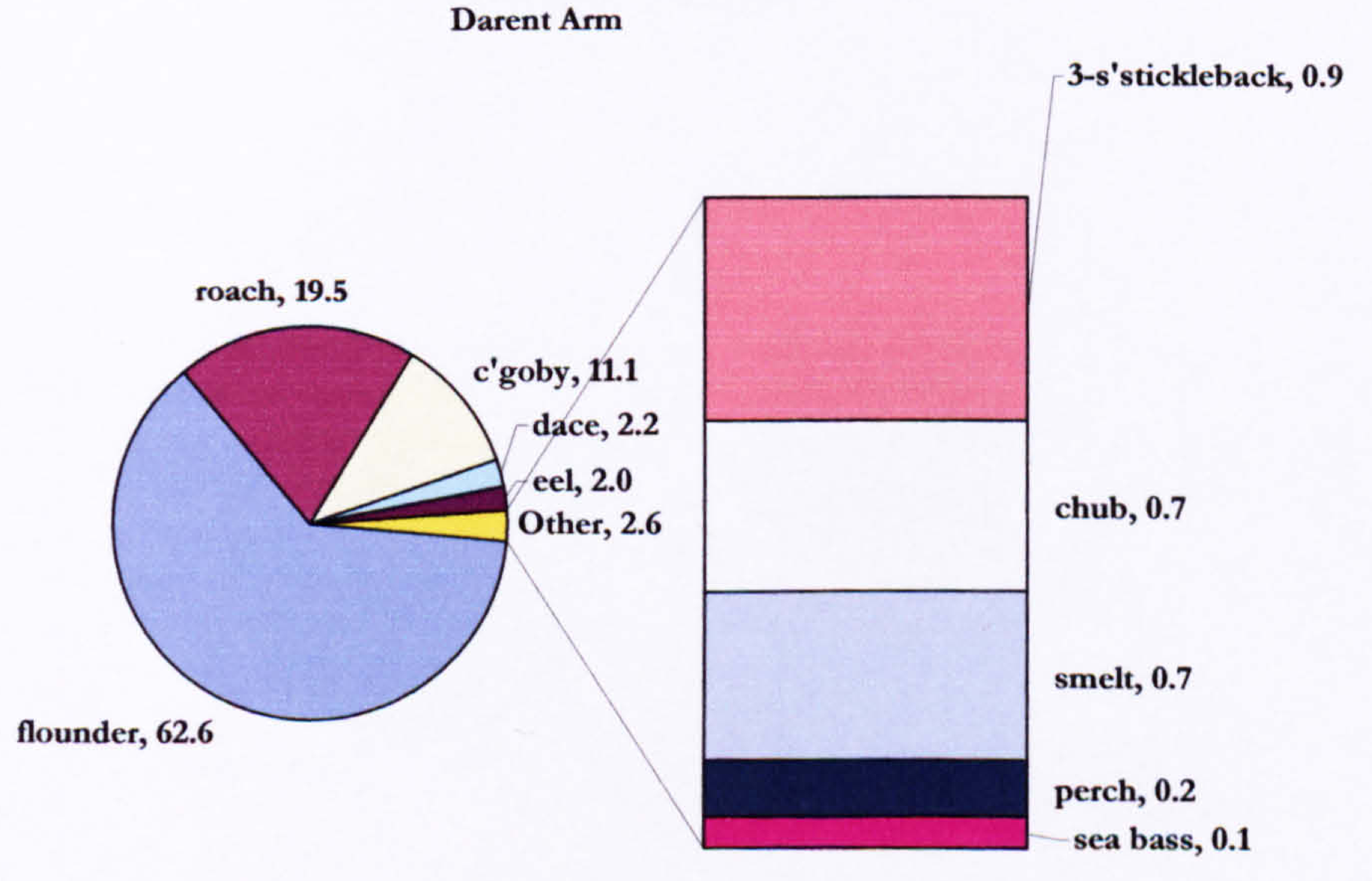


Figure 4.24 Frequency of occurrence (% proportion) of the most abundant species captured from the Crayford Arm of the Dartford Creek by the Environment Agency from June to September 2001

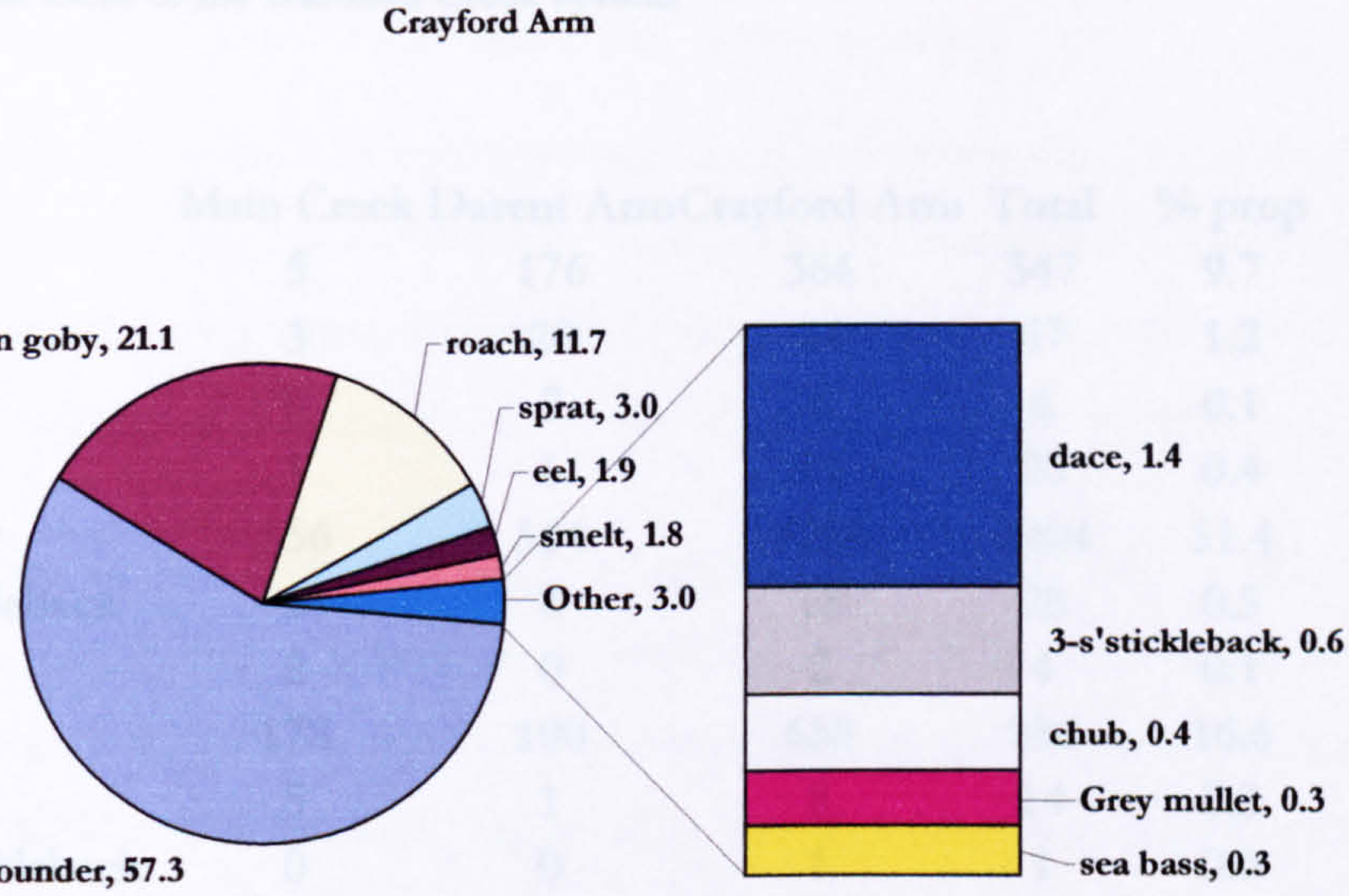
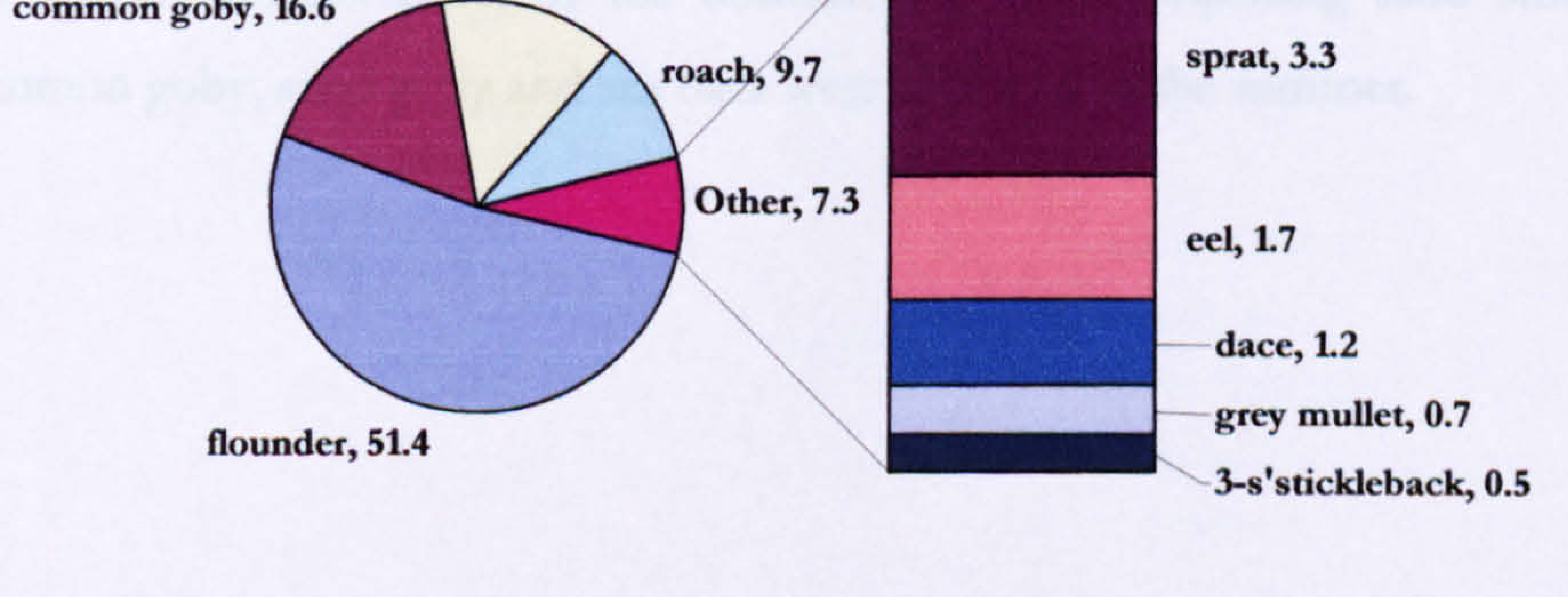


Table 4.17 shows the contribution of different species to the total number of fish sampled. Figure 4.25 shows the frequency of occurrence (% proportion) of the most abundant species captured from the Dartford Creek system by the Environment Agency from June to September 2001.

Table 4.17 The contribution of the different species (relative density and % proportion) to the total fish samples of the different areas of the Dartford Creek system

species	Main Creek	Darent Arm	Crayford Arm	Total	% prop
roach	5	176	366	547	9.7
dace	3	20	44	67	1.2
perch	0	2	4	6	0.1
chub	1	6	13	20	0.4
flounder	556	564	1784	2904	51.4
3-s'stickleback	2	8	18	28	0.5
bream	2	0	2	4	0.1
c'goby	178	100	658	936	16.6
sea bass	5	1	8	14	0.2
10-s'stickleback	0	0	1	1	0.0
herring	8	0	0	8	0.1
smelt	734	6	56	796	14.1
eel	20	18	58	96	1.7
Grey mullet	28	0	9	37	0.7
sprat	91	0	95	186	3.3
Total	1633	901	3116	5650	

Figure 4.25 Frequency of occurrence (% proportion) of the most abundant species captured from the Dartford Creek system by the Environment Agency from June to September 2001



Dartford Creek - Variation in species distribution between areas

In the Dartford Creek system 5650 individuals were caught of which the most abundant species were flounder (51.4%), common goby (16.6%), smelt (14.1%) roach (9.7%) and sprat (3.3%). Freshwater species, roach, dace, chub, bream, and perch together comprised only 11 % of the catch with the great majority of these caught from the Darent and Crayford Arms.

The dominant species of the two arms were flounder (62.6% and 57.3% in the Darent and Crayford arms respectively) and common goby (11.1% and 21.1% in the Darent and Crayford Arm respectively). Figure 4.22 shows the % proportion of the most abundant fish species of the main creek; Figure 4.23the Darent Arm; Figure 4.24 Crayford Arm and Figure 4.25 the entire Dartford Creek system. The most abundant species in the main trunk of the creek were smelt (44.5%) followed by flounder (34.0%) and common goby (10.9%). The estuarine group, smelt, three-spined stickleback and sprat were well represented throughout the creek system.

Victoria Dock Basin

Table 4.18 shows the relative species densities and frequency of occurrences (% proportions) of fish species captured from the Queen Victoria Dock Basin. A total of 11384 fish were caught over the year in the Victoria Dock Basin comprising 10 species. The most abundant species captured in the Queen Victoria Dock were sand smelt (75.1%), the smelt (16.0%), three-spined sticklebacks (5.0%), sand goby (1.5%), common goby (1.2%), eels (0.9%), and sea bass (0.8%). Flounder, roach, dace and perch together formed only 0.3% of the catches. Several species showed a marked seasonal variation in their occurrence and abundance in the dock. Roach and dace were only captured in the winter months. Most of the dominant species comprising sand smelt, smelt, sticklebacks, common goby, sand goby and sea bass were captured in the summer.

Table 4.18 The relative species densities and relative frequency of occurrences (% proportion) of fish captured in the Queen Victoria Basin from April 2001 to May 2002

	Queen Victoria Dock													
Species	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Total	% prop
sand smelt	763	1234	1811	2028	1638	614	380	81	2	0	0	0	8551	75.1
smelt	9	14	1	761	946	44	20	3	8	4	6	8	1824	16.0
3-s'stickleback	1	3	0	312	214	12	0	3	7	6	2	6	566	5.0
sand goby	3	7	32	48	66	8	0	4	0	3	0	1	172	1.5
c'goby	0	3	11	28	52	12	0	0	12	3	7	8	136	1.2
sea bass	9	0	1	14	34	19	0	8	4	0	0	1	90	0.8
dace	3	7	0	0	0	0	0	0	1	4	0	1	16	0.1
flounder	2	2	0	1	2	2	0	0	1	0	0	2	12	0.1
roach	0	0	0	0	0	0	0	0	2	8	1	0	11	0.1
perch	0	0	0	3	2	0	0	0	1	0	0	0	6	0.1
Total	790	1270	1856	3195	2954	711	400	99	38	28	16	27	11384	100.0
% prop	6.9	11.2	16.3	28.1	25.9	6.246	3.51	0.87	0.33	0.25	0.141	0.24		

Figure 4.26 shows the frequency of occurrence (% proportion) of fish species captured in from the Queen Victoria Dock Basin from April 2001 to March 2002. Figure 4.27 shows the monthly variation in fish numbers in the basins. High abundances occur between April to October and peak abundances in July and August. Sand smelt is the most abundant fish followed by smelt.

Figure 4.26 Frequency of occurrence (% proportion) of fish species captured in Queen Victoria Basin April 2001 to March 2002

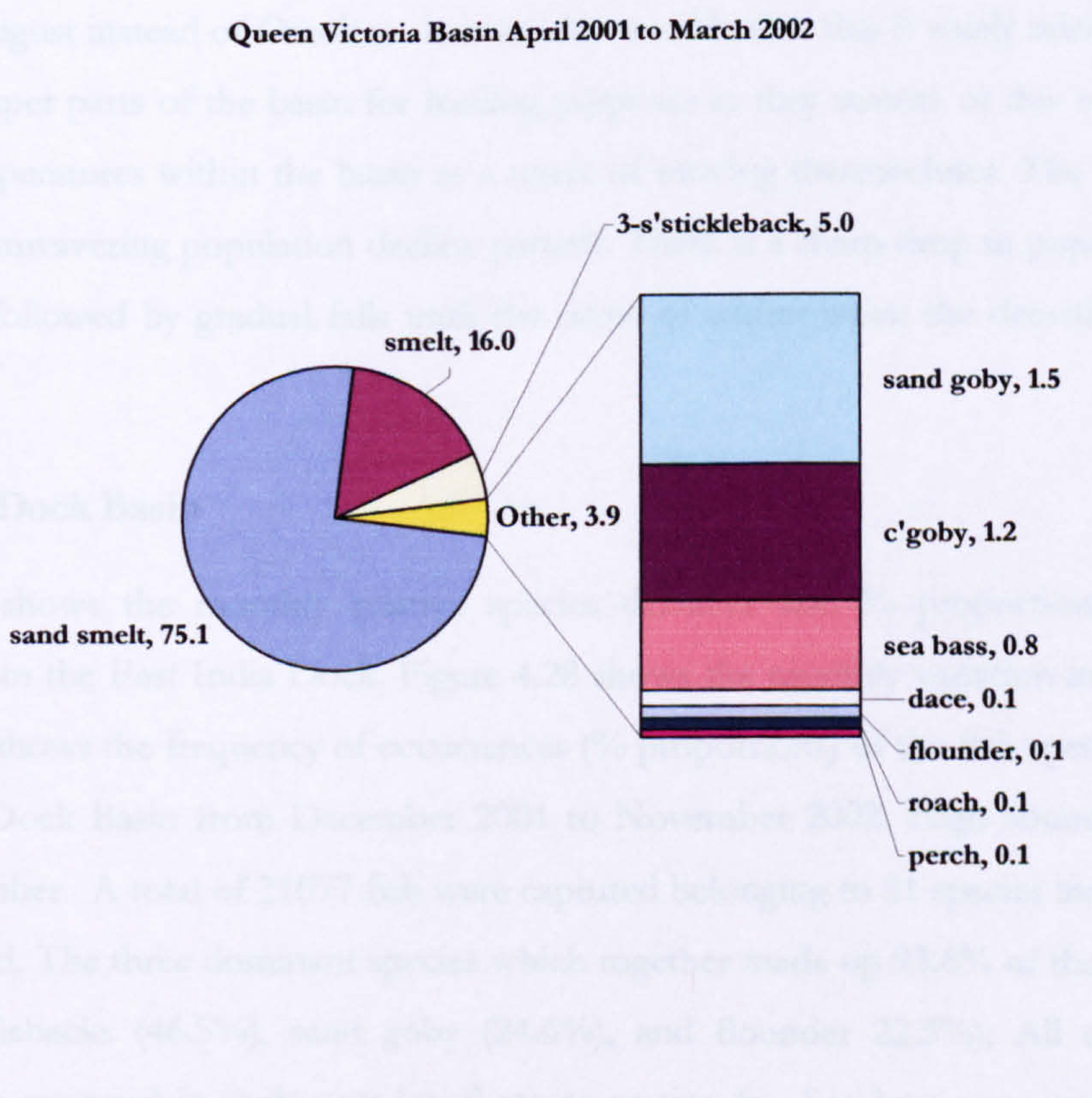


Figure 4.27 Monthly variation in fish numbers in the Queen Victoria Basin April 2001 to March 2002

Fish were present throughout the year in the marginal water of the basin. The populations assembled up rapidly from April through May and June and peaked in July. The pattern of population variation in this basin is very interesting. Unlike sites belonging to the main river and the East India Dock the peak population density occurred in July and the population decline started in August instead of October. It is not known whether this is solely related to migration of fish into deeper parts of the basin for feeding purposes as they mature or due to an early onset of the low temperatures within the basin as a result of moving thermoclines. The latter is very likely because of unwavering population decline pattern. There is a sharp drop in population densities in September followed by gradual falls until the onset of winter when the densities were stable but very low.

East India Dock Basin

Table 4.19 shows the monthly relative species densities and % proportions for fish species captured from the East India Dock. Figure 4.28 shows the monthly variation in fish numbers and Figure 4.29 shows the frequency of occurrences (% proportions) of the fish species captured in the East India Dock Basin from December 2001 to November 2002. High abundances occur from June to October. A total of 21077 fish were captured belonging to 21 species including the roach x bream hybrid. The three dominant species which together made up 93.6% of the total catch were 3 spined sticklebacks (46.5%), sand goby (24.6%), and flounder 22.5%). All of these dominant species were captured in their post larval stages as tiny fry. Sea bass were present in noticeable numbers (2.9%) whilst the remaining 16 species were each less than 1% of the total catch and comprised together about 3.5% of the total fish caught at this site. The highest relative densities were observed during the spring and summer seasons. The population densities crashed in October in a similar fashion as the main sites. This was related to the life history of the fishes present - spring being the breeding period when a large number of young of the year were present. During this period many species were captured in their post larval stages.

Table 4.19 The relative species densities and frequency of occurrences (% proportions) of fish captured in the East India Dock Basin from December 2001 to November 2002

	East India Dock Basin site													
Species	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Total	% Prop
s'goby	21	14	8	4	12	32	432	789	2344	5211	922	12	9801	46.5
dace	1	6	3	6	12	12	1243	900	2432	433	121	20	5189	24.6
smelt	2	1	1	3	5	8	3828	840	34	22	2	1	4747	22.5
bream	1	1	1	2	38	3	132	162	231	32	1	1	605	2.9
roach x bream	21	20	8	0	0	0	0	0	2	56	21	3	131	0.6
perch	2	1	1	0	0	0	66	32	8	2	1	0	113	0.5
roach	0	1	1	12	18	9	9	12	14	22	7	0	105	0.5
dab	0	0	0	18	12	9	8	32	5	1	0	0	85	0.4
chub	0	0	0	0	0	0	12	34	9	7	1	0	63	0.3
c'goby	0	4	1	5	17	0	13	12	2	1	0	1	56	0.3
gudgeon	1	1	0	8	4	1	12	17	6	1	3	1	55	0.3
3-s'stickleback	7	6	1	0	3	0	7	8	1	0	3	0	36	0.2
sand smelt	1	1	2	1	6	0	4	8	1	0	0	4	28	0.1
sea bass	3	1	3	1	2	1	1	1	2	2	4	1	22	0.1
plaice	0	0	0	0	3	0	12	1	1	1	0	0	18	0.1
mullet	0	0	0	0	3	0	1	3	0	0	0	0	7	0.0
flounder	0	0	0	0	0	0	3	2	1	0	0	0	6	0.0
eel	0	0	0	0	0	0	4	0	0	0	0	0	4	0.0
10-s'stickleback	0	0	0	0	1	0	1	1	0	0	0	0	3	0.0
bleak	0	0	0	0	0	0	2	0	0	0	0	0	2	0.0
grey mullet	0	0	0	0	0	0	1	0	0	0	0	0	1	0.0
Total	60	57	30	60	136	75	5791	2854	5093	5791	1086	44	21077	
% prop	0.3	0.3	0.1	0.3	0.6	0.36	27.5	13.5	24.2	27.5	5.15	0.21		

Figure 4.28 Monthly variation of fish numbers in the East India Dock Basin December 2001 to November 2002

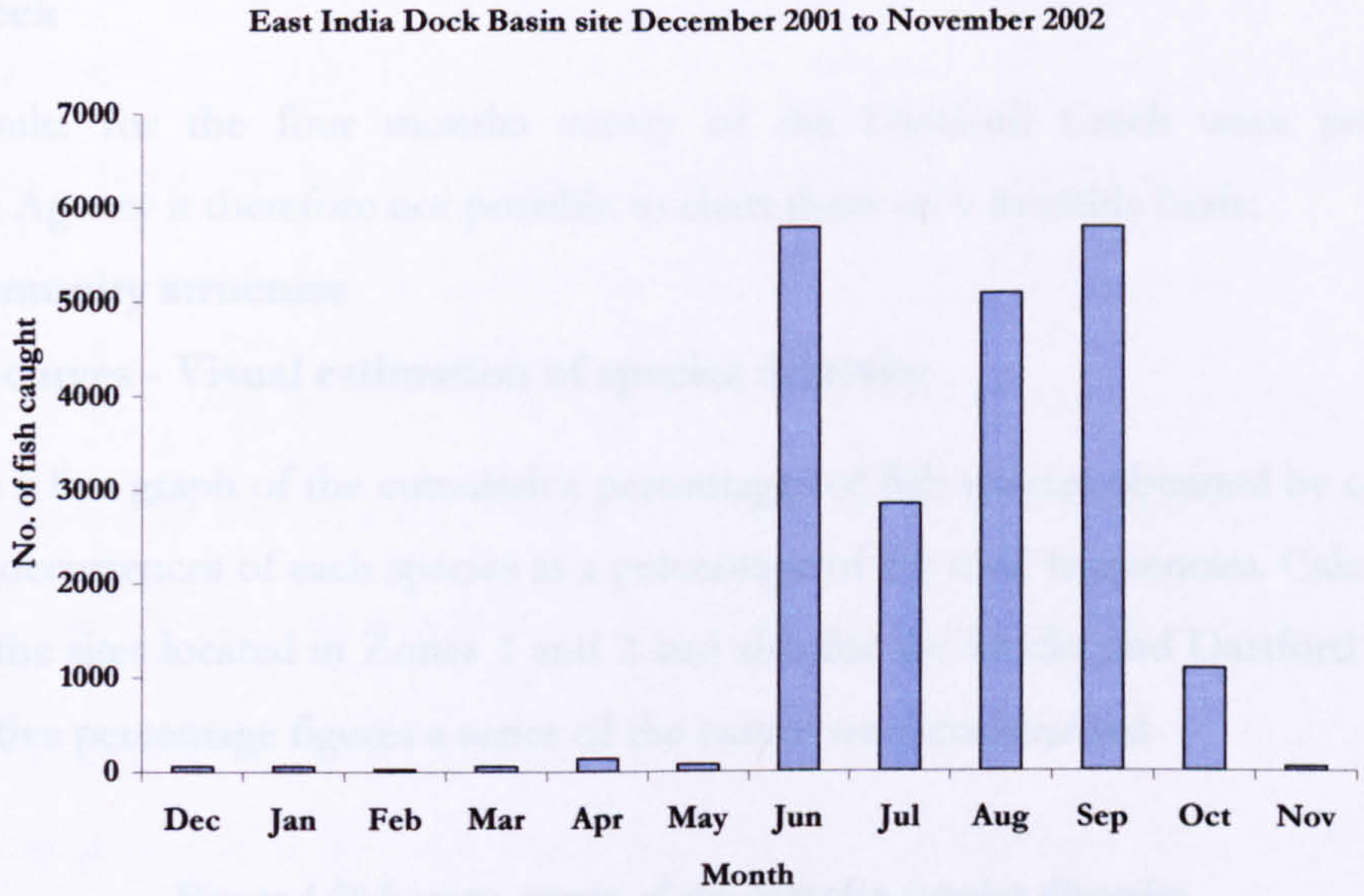
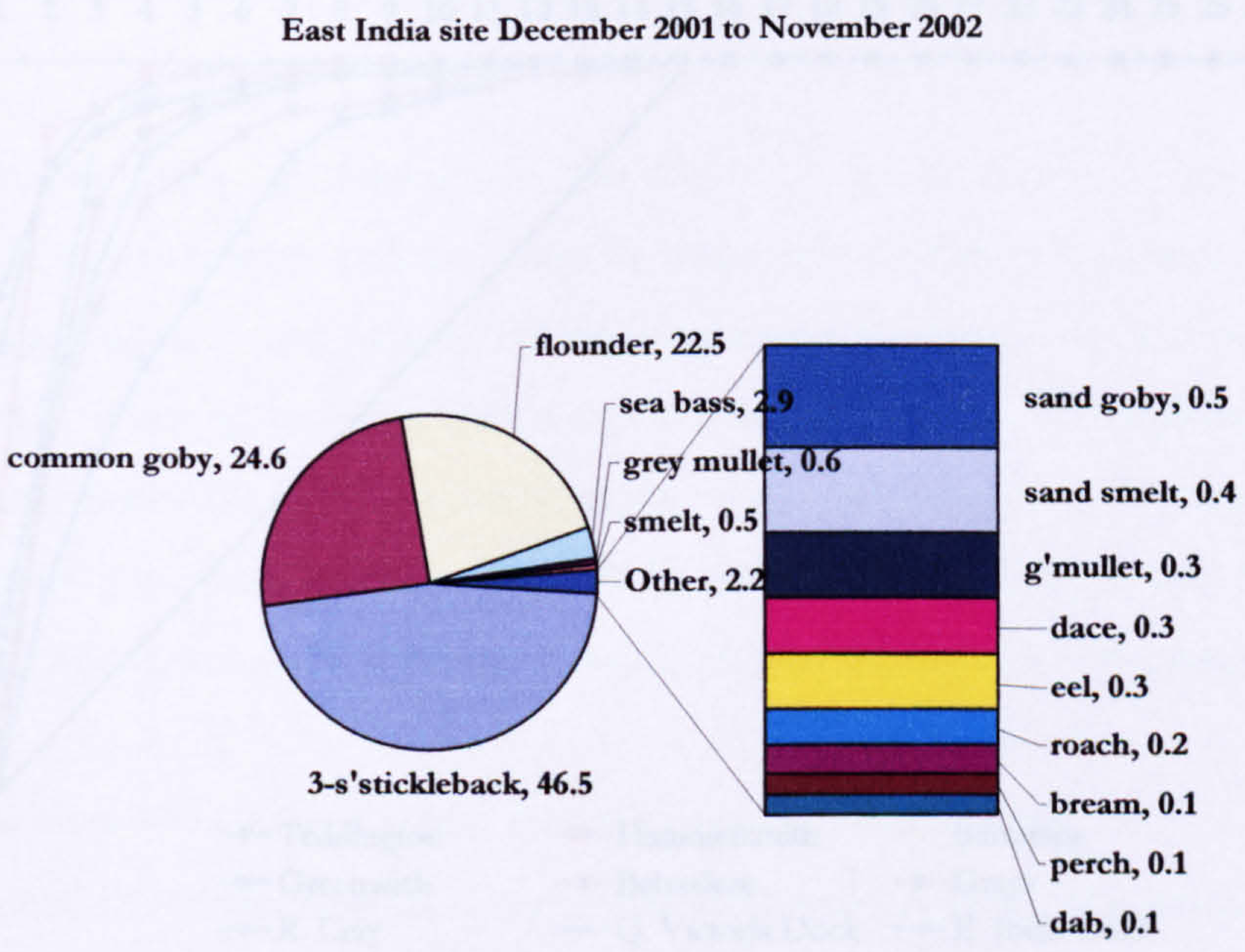


Figure 4.29 Frequency of occurrence (%proportion) of fish species captured in the East India Dock December 2001 to November 2002



Dartford Creek

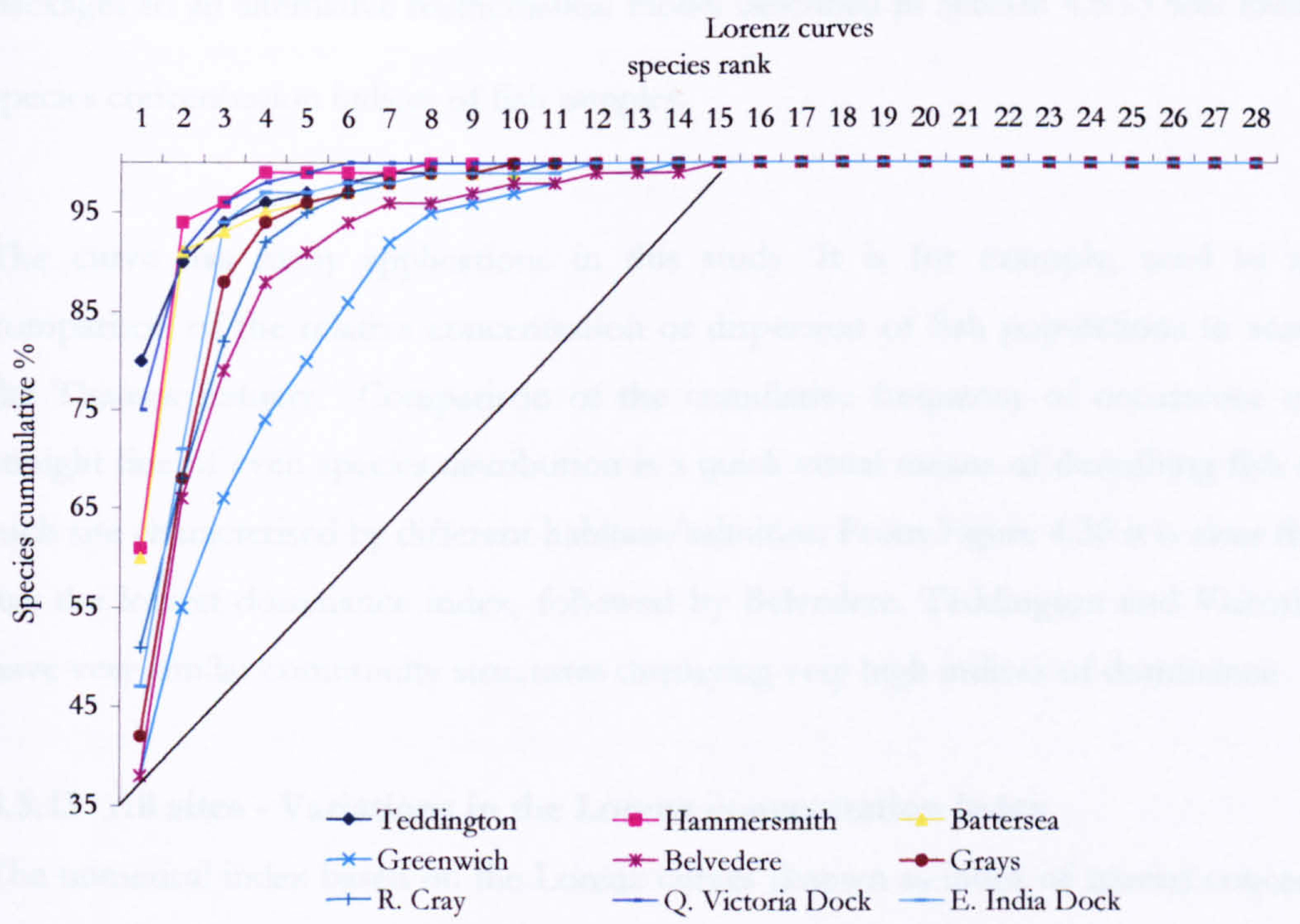
The fish results for the four months survey of the Dartford Creek were pooled by the Environment Agency it therefore not possible to chart them on a monthly basis.

4.5.12 Community structure

The Lorenz curves - Visual estimation of species diversity

Figure 4.30 is a line graph of the cumulative percentages of fish species obtained by calculating the frequency of occurrences of each species as a percentage of the total frequencies. Calculations were made for all the sites located in Zones 1 and 2 and also for the Docks and Dartford Creek. From these cumulative percentage figures a series of the curves were constructed

Figure 4.30 Lorenz curves of site samples species diversity



It is evident from Figure 4.30 that if every species had exactly the same percentage frequency of occurrence), (i.e. if species were evenly distributed the cumulative curve would be a straight line as indicated by the 'even distribution scenario' line. The 45 degree line shows the situation when there is an even distribution of fish species i.e. 100% of the population are distributed in 100% of the species. This is called the line of absolute equality. The closer the Lorenz curve of a site is to the

45-degree line the more equal the distribution of fish species of the site represented by that curve is. The more the Lorenz curve bends away from the 45-degree line of absolute equality, the less equal is the distribution of fish. The ratio between the areas of the curves representing a site and the whole triangle under the line of absolute equality is called the concentration index. If a site had a completely even distribution of species its reprehensive areas would be the same and the concentration index would be zero. If the population were distributed so unevenly that one fish had 100% of the entire site's distribution and the rest of the expected population had nothing the concentration index in this case would be 1. The closer the concentration indices of sites are to 1, the greater the inequalities of species distribution for that site. However, obtaining the ratios between the areas of the curves and the whole triangle was difficult using common statistical packages so an alternative mathematical model described in Section 4.5.13 was used to derive the species concentration indices of fish samples.

The curve has many applications in this study. It is for example, used to make a crude comparison of the relative concentration or dispersion of fish populations in zones 1 and 2 of the Thames Estuary. Comparison of the cumulative frequency of occurrence curve with the straight line of even species distribution is a quick visual means of describing fish diversity from each site characterised by different habitats/salinities. From Figure 4.30 it is clear that Greenwich has the lowest dominance index, followed by Belvedere. Teddington and Victoria Dock basin have very similar community structures displaying very high indices of dominance.

4.5.13 All sites - Variations in the Lorenz concentration index

The numerical index based on the Lorenz curves (known as index of species concentration) gives greater precision. The index was calculated by:

Icon = (A – R)/ (M – R), where ***Icon*** is the index of concentration, **A** is the site cumulative totals of the species, **M** is the maximum cumulative percentage of the frequencies in rank 1 and **R** is the regional cumulative percentage total. Because there are 27 species **M** is 2700 (including sprat recorded in the Dartford Creek by the Environment Agency in their 2001 surveys). The crude index therefore is a measure of the extent to which any site, included in the whole region surveyed, differs from absolute concentration of frequencies into one species. The concentration Index values for Teddington, Hammersmith, Battersea, Greenwich, Belvedere and Grays are 0.70, 0.67, 0.55, 0.36, 0.02 and 0.67 respectively. The results for the main river show least species concentration in the mid estuary i.e. Belvedere and Greenwich, with a rising index to the seaward end at Grays, and up-stream to Teddington. This implies that a few species are very abundant at either end of the estuary and a wider range of less abundant species occur in the middle which is in accordance to the accepted views of species concentration in estuarine environments. The reason for this apparent lower concentration of species at Greenwich and Belvedere is that these sites do not have huge concentrations of post larval fish at particular times of the year. Post larval flounder raise the concentration index at Hammersmith and to a lesser extent Battersea. Sea bass raise the concentration index at Grays where 1+ are very numerous, possibly taking advantage of the warm water in this area. At Teddington the very large population of roach dominates the community and hence raise the concentration index at this site.

The docks appear to offer a rather specialised environment and the concentration index is very high because one or two species are very successful. In Victoria Dock (icon = 0.75) the sand smelt is dominant whereas in East India dock (icon = 0.63) it is the common goby and three spined sticklebacks which are dominant. Dartford Creek (icon = 0.73) displays a high dominance for flounder.

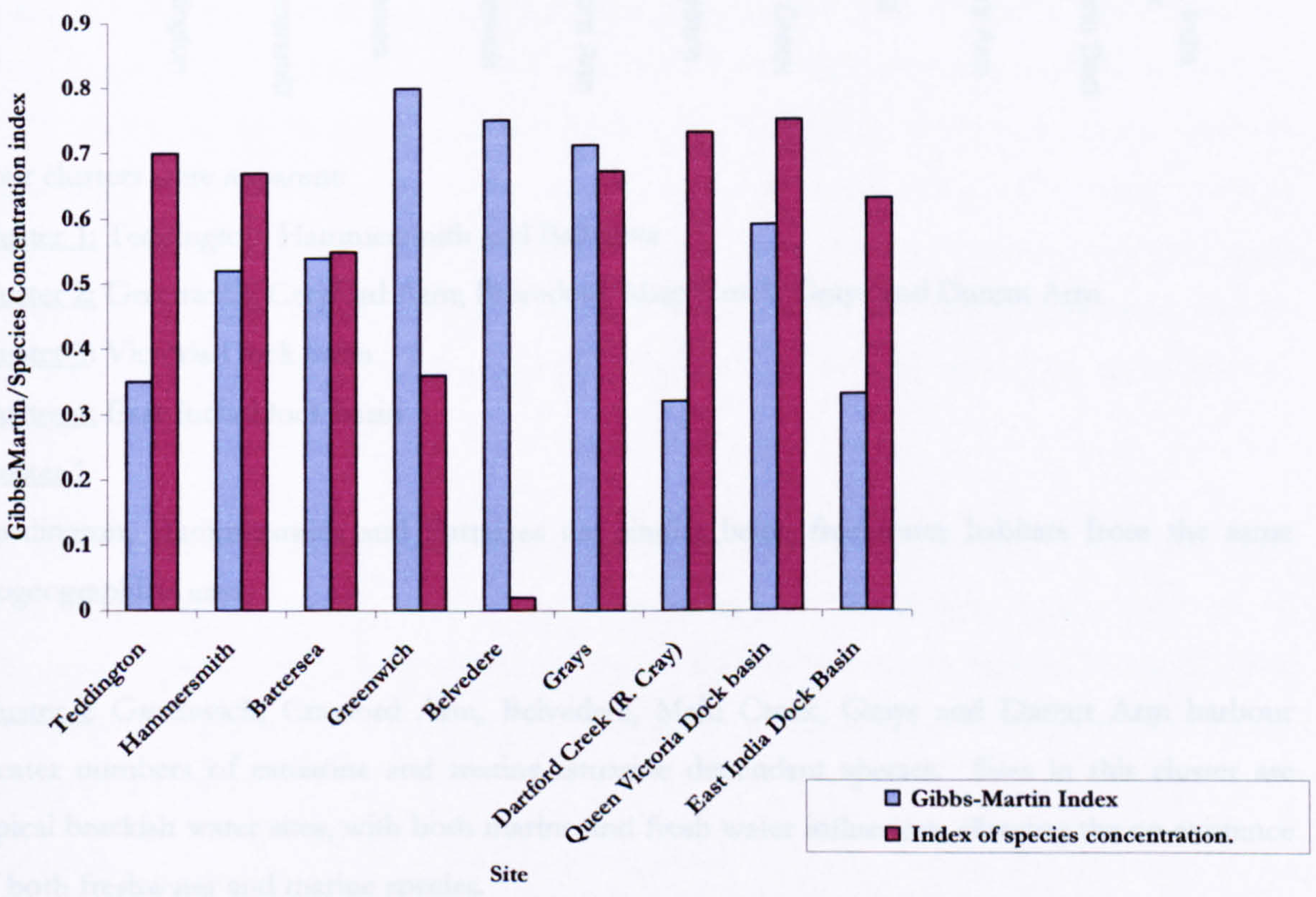
Gibbs-Martin Index of Species Diversity - all sites

The results for the calculations involving data for sites along the upper and middle Thames Estuary, Dartford Creek, East India Dock basin and Queen Victoria Dock basin are tabulated in Table 4.20. A column plot graph of the indices is depicted in Figure 4.31. The range of the Gibbs-Martin index runs from 0.32 (low diversity or high dominance in the Dartford Creek) to 0.80 (high diversity or low dominance in Greenwich and Belvedere 0.75). Hammersmith and Battersea have Gibbs-Martin Indexes of 0.52 and 0.54 respectively); East India Dock Basin (0.33), Teddington (0.35), Hammersmith (0.52), Battersea (0.54) and Victoria Dock Basin (0.59). They have rather less diversified communities than the mid estuarine sites because of the high populations of roach or flounder, three-spined stickleback or goby or two or three in the list. As expected, Gibbs-Martin index reflects Lorenz i.e., when the GB is high the Icon is low.

Table 4.20 Gibbs-Martin indexes of species diversity and concentrations in sites along the Zones 1 and 2 of the Thames Estuary, Dartford Creek system, Queen Victoria and the East India Dock Basins

Site	Gibbs-Martin Index	Lorenz index of cons.
Teddington	0.35	0.70
Hammersmith	0.52	0.67
Battersea	0.54	0.55
Greenwich	0.8	0.36
Belvedere	0.75	0.02
Grays	0.71	0.67
Dartford Creek (R. Cray)	0.32	0.73
Queen Victoria Dock basin	0.59	0.75
East India Dock Basin	0.33	0.63

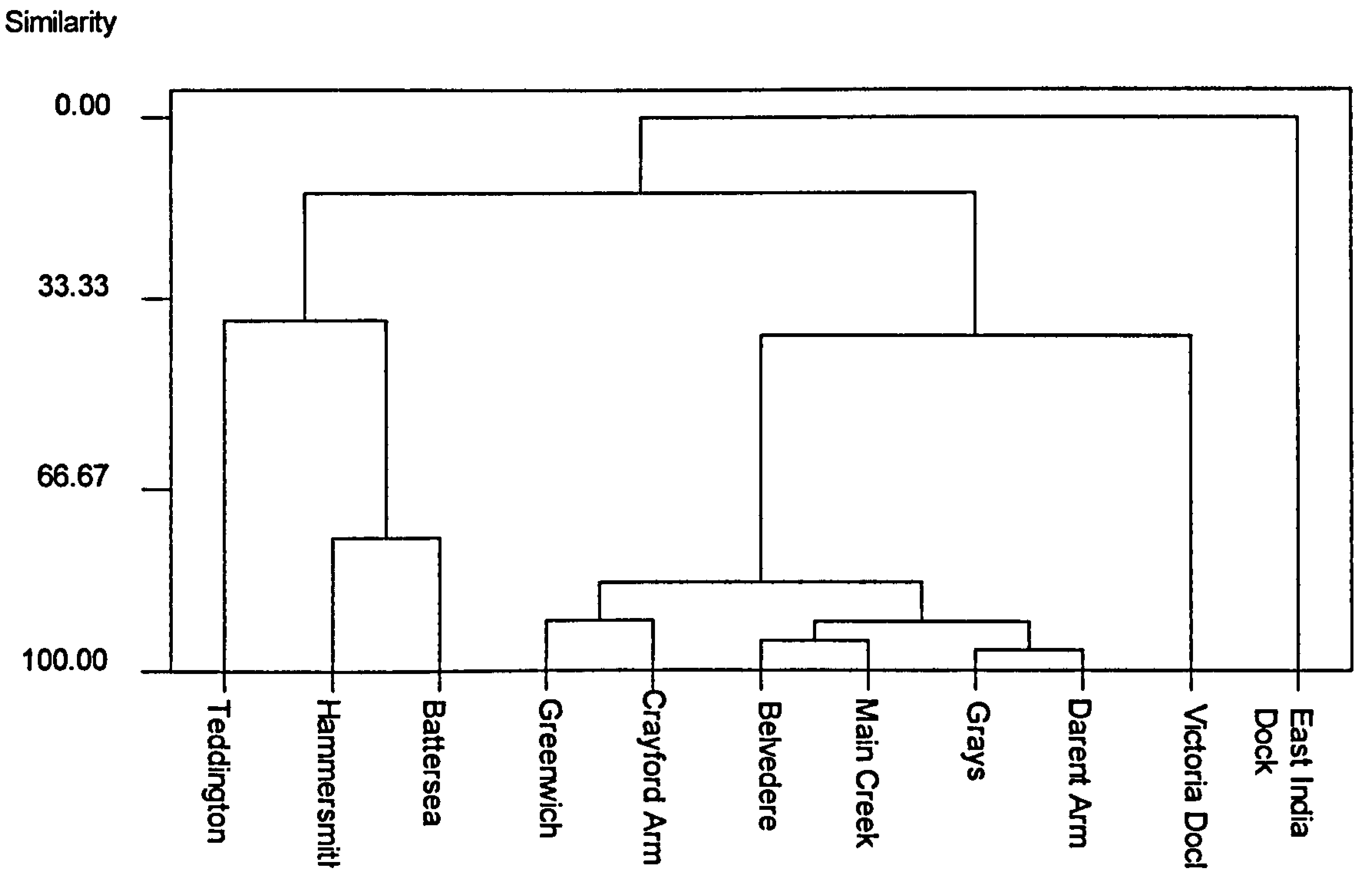
Figure 4.31 Column graph of the Gibbs-Martin Indexes of species diversity and the Lorenz index of species concentration or dominance



4.5.14 Cluster Analysis: site similarities

A cluster analysis was performed on the fish species relative abundance data for all the sites. Figure 4.32 is a cluster graph (dendrogram) showing the similarity relationships of the different sites with respect to their fish assemblages and community structures.

Figure 4.32 Cluster graph showing the similarity of sites in relation to their species assemblages



Four clusters were apparent:

Cluster 1: Teddington; Hammersmith and Battersea

Cluster 2: Greenwich; Crayford Arm; Belvedere; Main Creek; Grays and Darent Arm

Cluster 3: Victoria Dock basin

Cluster 4: East India Dock basin

Cluster 1

Teddington, Hammersmith and Battersea are similar being freshwater habitats from the same biogeographical area

Cluster 2 Greenwich, Crayford Arm, Belvedere, Main Creek, Grays and Darent Arm harbour greater numbers of estuarine and marine-estuarine dependant species. Sites in this cluster are typical brackish water sites, with both marine and fresh water influences, allowing the co-existence of both freshwater and marine species.

Cluster 3

The Queen Victoria basin was different in structure from the rest because it had dominance by one species sand smelt (75%). It is the only site showing dominance by a single species all year round and acting as a refuge for sand smelt and smelt.

Cluster 4

The East India Dock basin has species evenness and richness similar to that of the entire region indicative of high habitat heterogeneity.

4.6 Overview of individual species

4.6.1 Freshwater species

Cyprinidae

Several members of this family exist mostly as freshwater inhabitants.

Roach *Rutilus rutilus* is said to be abundant in almost all the rivers throughout the temperate parts of Europe, and in the UK appears to be a very common fish, inhabiting most of the rivers, but preferring those that are slow in their course, frequenting the deepest parts by day, and by night feeding on the shallows (Maitland and Campbell 1992 and Pivnicka and Cerny, 1998). Previous studies describe roach as the most abundant freshwater species in the Thames Estuary (Wheeler, 1979, Araujo 1992, Colclough et al (1999 and 2000). In the present study, roach accounted for 80.8%, 45.3% and 41.7% of the total fish captured in Teddington, Hammersmith and Battersea respectively. These sites are located in the low salinity (Zone 1) of the estuary. The species seems to have multiple spawning periods: 0+ cohorts of roach are present throughout the year in the upper estuary. The 1+ cohort of roach is present through out the upper and middle estuary except at the high salinity site of Grays. They were also collected from the Dock Basins and the upper Arms of Dartford Creeks.

The significance of roach declines markedly at Greenwich (7.2%), Belvedere (1.6%) and Grays (0.0%) located in the brackish water (Zone 2) of the estuary. The decline in the significance of roach in the brackish water sites of Greenwich and Belvedere is due to increased osmotic stress imposed on the species in this environment. The salinity at Grays site (15-28 ppt) is lethal for the survival of the species.

Dace (*Leuciscus leuciscus*) and roach are somewhat allied in their habits, and a little so in their appearance; but the former is not so plentiful as the latter, nor is it so generally dispersed, being comparatively more local. Dace inhabits Italy, France and Germany, and in the UK is found in the deep and clear water of quiet streams (Wheeler, 1969b; 1979 Maitland and Campbell 1992 Pivnicka and Cerny 1998). In the British Isles, dace is native to South East England, but has been redistributed over much of England and Wales and the Border Rivers of Scotland. Its principal habitat is the middle reaches of clean, fast flowing rivers and streams but it also inhabits lowland, slow flowing rivers (Maitland and Campbell 1992). It is relatively abundant in the tidal Thames. Dace spawn between February and April, being the earliest breeding cyprinid in Britain. The young grow rapidly, reaching about 60-80mm in their first year. Most mature in the third or fourth year and keep growing slowly thereafter. They rarely live beyond seven years or eight years. Dace is the only freshwater species known to spawn in the tidal Thames and has been observed spawning on gravel as far downstream as Wandsworth (Colclough, 1992, Myers, 1988).

In Dartford Creek, dace were found in both the Crayford and Darent Arms of the creek, although they were more abundant in the Crayford Arm. A few 0+ were captured in the East India dock basin in June. These may have most likely entered the basin during high tide and remained there. Only a few dace were also caught in the Queen Victoria dock basin in the summer months but were all 1+-year class individuals. The low occurrences of this species in the basins are due to the salinity ranges, being high but at the same time, the species being fully physiologically adjusted to brackish water salinity conditions found in these basins. While the species cannot probably spawn in the basin, it can survive when in there.

In this study, the 0+ dace first appeared in June at Teddington. However, a small percentage of 0+ were also captured in Hammersmith and Battersea also supporting the old supposition that this species spawns as far downstream as Hammersmith. No 0+ classes were captured in the brackish water reaches of Greenwich, Belvedere and Grays. However, the 1+ class were present throughout the estuary except at Grays; although again like roach they were sparsely present in the reaches of Greenwich and Belvedere. The highest congregation of the 1+ dace occurred at Teddington where they made up 10.6% of the total site fish population although trailing behind roach by 70.2%. Overall dace accounted for 1.2% of the total fish captured in Dartford Creek, 1.4% in the Crayford Arm and 2.2% in the Darent Arm of Dartford Creek. They were present in sub 1.0% proportions in the brackish water systems of Victoria and East India Dock Basins and very occasional in the main Arm of Dartford Creek.

According to Pivnicka and Cerny (1998) bream (*Abramis brama*) is an inhabitant of many of the lakes and rivers of the continent of Europe generally, even as far north as Norway and Sweden. It is a fish of lowland areas and prefers rich, muddy, weedy lakes, reservoirs and slow flowing rivers. It is capable of withstanding very low levels of oxygen and therefore survives poor conditions for considerable periods. In the UK it appears also to thrive best in large pieces of water, or in the deep and most quiet parts of rivers that run slowly, being found in many counties, and particularly in some of those that contain lakes and canals of considerable extent. The lakes of Cumberland, and some of the most extensive lakes in Ireland, produce large quantities of bream of great size. Of the rivers near London producing bream, the Mole and the Medway are the most noted; it also occurs in the Regent's Canal (Maitland and Campbell, 1992). Bream swim in shoals, feeding on worms, and other soft-bodied animals, with some vegetable substances; and if the water they inhabit suits them, which is generally the case, as they are hardy in their nature, they grow rapidly, and spawn in May. In the present study, bream was found to be relatively uncommon confirming earlier studies at the Thames Estuary. 0+ bream were occasionally encountered in Battersea and Greenwich, casting doubts on their main spawning area. However 1+ bream are widely distributed though not evenly. By far the greatest congregation surprisingly occurred in Greenwich (9.9%). When comparing the 0+ and 1+ bream populations it is apparent that this species recruits successfully in the estuary. Bream were not present in the Victoria Dock Basin and were rare (<1% proportion) in the East India Dock Basin. The species was also found in low numbers (<1% proportion) in both arms of the Dartford Creek.

Gudgeon is a freshwater fish, typically found in relatively fast flowing rivers and streams with a clean stony substrate. Gudgeon (*Gobio gobio*) is found in many streams that in their course flow over gravely soils: it generally occurs in slow flowing rivers that have shallow scours over which the current of the water is increased. The Thames, Mersey, Colne, Kennet, and the Avon, produce an abundance of gudgeon (Wheeler, 1979 and Maitland and Campbell, 1992). In this study gudgeon was abundant at Teddington (2.9%), occasional in Hammersmith, Battersea, Greenwich and East India Dock.

Chub (*Leuciscus cephalus*) is a well-known fish that is common in the Thames, and many other rivers of England: it is said to be plentiful in the Wye, and other rivers of Wales. It is also recorded as an inhabitant of the Annan, and other rivers in the south of Scotland. Chub is closely related to the dace and inhabits similar habitats but is much less salinity tolerant. Spawning takes place from May to June when temperatures rise above 12°C (Maitland and Campbell 1992). Chub are mainly found in Zone 1 of the Tidal Thames, and are also found in the Crayford and Darent Arms of Dartford Creek. In its nature the chub is timid, frequenting deep holes in the more quiet parts of the sides of the stream, and sheltering itself generally under or near any bush or tree that will screen it from view. It feeds on worms and on insects in their various stages. Chub are known to be particularly intolerant of high salinity and were not found in the mid Estuary and only one individual was captured from the docks..

Many members of the Cyprinidae family form hybrids when shoals of spawning fish mingle on the spawning grounds, when two or more species share a common type of site and time of year. Occasionally, however, a ripe male of one species will apparently deliberately mingle with actively spawning fish of another species and take part in the process. The greatest amount of hybridisation takes place between the more closely related species, and is particularly likely to occur under unnatural conditions, where, for instance, one species has been introduced to a new locality. Hybrids are often recorded as common in certain waters (as the rudd x bream in Lough Erne, Ireland), but are rare in other waters in which both parents occur. Most hybrids are sterile. Females are very rare. In the hybrid between the roach and the bream (*Rutilus* x *Abramis*), fertile offspring are common, and certain populations in isolated waters have a complex interbred ancestry.

Bleak (*Alburnus alburnus*) is a well-known small species inhabiting many of the rivers of Europe, and is found in this country in most, if not all, those which produce the roach and the dace. The Thames, the Lea, and the New River produce bleak in considerable numbers (Maitland and Campbell, 1992). They swim in large shoals, spawning in May; and at that time the head and gill-covers are rough to the touch.

Percidae

Perch (*Perca fluviatilis*) occur in lakes and slow flowing rivers and canals throughout most of Europe. They spawn in the late spring when the water temperature is between 10 and 15°C. They are relatively sensitive to water quality and require a moderately high level of dissolved oxygen (Wheeler 1979). This species is reasonably abundant in the upper estuary and 1+ individuls occur in small numbers at the other sites except Grays and the main Dartford Creek where salinity is probably above their tolerance range. 0+ individuals were only captured in Teddington. In Teddington the annual relative proportion of perch is (2.3%).

Anguillidae

Eels have a distinctive elongated body and long dorsal and anal fins. The commonest representative of the family in northern European waters, the European eel *Anguilla anguilla*, breeds in mid-Atlantic and larvae are transported to coastal waters by oceanic currents. The juvenile stages are closely associated with freshwater, and hence eels are found in greatest abundance near Estuaries (Naismith and Knight 1988; Holmgren, and Wickström, 1988; Naismith & Knights, 1993). This species enters the Thames Estuary in April and May as elvers. Eels were not caught in very large numbers during the survey but were present in both Zones and all types of waters but constitute less than about 0.1% of all fish caught. It is however, important to note that the fishing method used was not the most appropriate for capturing eels. Many were observed escaping through the net mesh.

4.6.2 Marine - Estuarine dependants

Serranidae

Sea Bass (*Dicentrarchus labrax*) was the third most commonly caught fish overall. Sea bass were recorded in significant proportions from the Hammersmith (Tables 4.3 to 4.8 and 4.6 to 4.19). The largest numbers caught were at Greenwich as small post larvae. At Grays the 1+ year classes were collected throughout the seven months of survey. This fish is not tolerant to fresh water (though they are known to permanently inhabit river estuaries and coastal lagoons in regions of Europe (Wheeler 1969b; Barnes, 1994). They are also associated with warm industrial waters of power stations. Grays has a large grain processing factory which uses the river water for cooling purposes. This water is discharged very close to the fish sampling site potentially making the locality a very attractive site for the species. Sea bass was present in very low numbers at Hammersmith but was absent from Teddington.

Pleuronectidae

This family of right-eyed flatfish comprise large-bodied species of which several are commercially exploited (Rogers *et al* 1998). In other studies juvenile Pleuronectids dominate the catch in all regions of river mouth surveys in South East England (Hutchinson and Hawkins, 1993). The best known Pleuronectid, the plaice *Pleuronectes platessa,* is common throughout the inshore waters of England and juveniles occupy sandy and muddy nursery areas in all coastal regions. According to Rogers *et al* (1998) in coastal areas during September, 0-group plaice are most abundant in the intertidal zone and over 25% of fish are found in water less than 1 m deep. The flounder *Platichthys flesus,* although superficially similar to the plaice and able to interbreed with it, is of limited commercial value. It is most abundant in and close to estuaries and is often found in fresh water, though it breeds in the sea (Hutchinson and Hawkins 1993). Juvenile dab *Limanda limanda* are numerous in sandy coastal waters and are often associated with juvenile plaice. In this study Flounder were recorded at very high frequencies from May 2000 to April 2001 in Hammersmith (45.7%) and Battersea (46.3%) and in moderate amounts in Greenwich (24.4%), Belvedere (38.1% - from May to September 2000) and Grays (20.9% from October 2000 to April 2001). Teddington had less than 1.0% of flounder in its total fish community. The reason why Hammersmith and Battersea have such a high percentage of flounder in its annual total of fish population is because these sites are located within the Primary Nursery Areas (PNA) of this species in the Thames Estuary. This species is not present in high numbers after July due to mass migration into the lower estuary and to the North Sea using selective tidal currents (Wheeler, 1979; Hill, 1991; Araujo 1998 and 1999). On the other hand 1+ year classes were present in Greenwich, Belvedere and Grays where they were collected throughout the survey periods of these sites. No post larval stages of flounder were collected in Grays site and only moderate numbers were collected in Greenwich and Belvedere sites.

Like sea bass young plaice and dab utilise the estuary as a nursery ground but unlike sea bass they are most abundant at the seaward end of the mid Estuary and become progressively less numerous upstream but like bass are found in small numbers as far as Battersea and Hammersmith.

Mugilidae

Mullet (*Mugil labrasus*) were caught from several sites on the estuary and creeks and docks. Their numbers are probably underestimated as they tend to leap out of the seine net. It is thought that the adult of this species are a daily foraging visitor coming up and down river with the prevailing tide (Araujo *et al* 1998).

Clupeidae

Herring (*Clupea harengus*) is a shoaling, open water fish living near the surface or in mid-water. It is common both offshore and in coastal waters, and the young are particularly abundant in estuarine conditions (Lithgoe and Lithgoe 1971). However, although the presence of this species in the Thames Estuary is well recorded throughout the past two decades it was only captured at Grays in this study. This low catch for this species is related to the distances of sampling from the sea. This reaffirms the fact that this species only visits the mid estuary at high water and the chances of catching it at low water when all sampling was carried out in the edges of the reaches of the Thames Estuary were much reduced. Herring is recorded to be common in the lower Tideway from late autumn to the spring (Wheeler, 1979, Araujo 1992, Araujo *et al* 1998 and 1999, Colclough et al 1999 and 2000)

Sprat (*Sprattus sprattus*) is an abundant inshore fish in the coastal waters of northern Europe. They are particularly common in estuaries and bays over sandy bottoms. They are planktonic feeders, eating large quantities of small crustaceans, and fish larvae (Wheeler 1979 and Lithgoe and Lithgoe 1971). Spawning takes place in the spring and summer. The eggs are planktonic and the young drift as they grow. Sprat is a close relative of herring and is recorded as always being an important fish in the Thames Estuary, (Wheeler, 1979 and Araujo, 1992). According to these studies, in the tidal Thames, sprat migrates up to the Barking and Green Hythe area in the winter months. A permanent shoal of sprat is said to exist in the area around Queen Elizabeth Bridge, Dartford, and is very likely that any sprat sampled in Dartford Creek and the mid estuary originates from this population (Colclough *et al* 2000). Substantial numbers of sprat, including young-of-the-year were captured in the main Dartford creek. This supports the fact that they are very common in this area of the tidal Thames. Beyond these areas of the creek, no sprat was captured in any other site including the upper reaches of the mid and upper reaches of the estuary as well as the dock basins.

4.6.3 Estuarine Residents

Estuarine residents are species which breed and mature in the tidal brackish water environment of the estuary. They spend their whole lives in the estuary and reproduce without recourse to migration.

Gasterosteidae

Sticklebacks are well known members of coastal fish communities and most can survive in marine or fresh water. Most species are small cigar shaped; scale-less fish with sharp dorsal spines and a spine on each pelvic fin (Lithgoe and Lithgoe 1971 and Barnes, 1994). Of the three species caught on the survey, the three-spined stickleback *Gasterosteus aculeatus* is most closely associated with freshwater, although it can be found among marine algae near the shore. The fifteen-spined stickleback *Spinachia spinachia* has a characteristically long, slender body with 15 spines along the back, and is found in only fully saline coastal waters. It is relatively abundant in shallow waters of the south coast, where most individuals were found in water less than 5 m deep (Beaumont and Mann, 1984 and Barnes, 1994). In this study the nine-spined stickleback *Pungitius pungitius*, which is also a small coastal dwelling fish, has only been found on a few occasions in shallow water in Belvedere site. Three species of stickleback were found during this study - the 3, 9 and 15 spined sticklebacks. The 9-spined stickleback was captured from the Battersea, Greenwich and Belvedere sites. The 9-spined stickleback is found in shallow waters of lakes and rivers and is often found in coastal brackish waters of low salinity. It is not as tolerant of saline conditions as the three-spined stickleback and does not occur in full sea conditions around Britain, (Wheeler, 1979 and Rogers *et al* 1998). This is probably why it was restricted to the Hammersmith, Belvedere and Greenwich sites. The fifteen-spined stickleback was captured at Greenwich, Belvedere and East India Dock. This species is said to be rare in the Thames estuary; however, it may have been under detected because of its marked similarity with the nine-spined stickleback. The three-spined stickleback is one of the most widespread fish in the British Isles. The three-spined stickleback is found in the sea (Lithgoe and Lithgoe 1971 and Rogers et al 1998 and in coastal waters as well as freshwater (Maitland and Campbell, 1992).

The three-spined stickleback spawns between March and July. The male builds a nest into which it drives the female. After spawning, he guards the eggs and subsequently the fry for a short time, Barnes (1994). This fish was present throughout the localities sampled and all the year round. It was however more abundant in the East India Dock Basin where thousands were captured in June, July, August and September. This is probably due to the protection provided for spawning in the *Phragmites* reed bed, the shallow foreshore and calm water of the basin. In the Thames estuary, this small spiny fish was abundant from Hammersmith to Belvedere. Most 1+ were 40-70mm in length, but on occasions, especially in Belvedere site up to 100mm long individuals were captured.

Gobiidae

This family of small inshore fish contains many species of which the commonest gobies are important members of the community, both as predators and prey. The common goby is widespread in the estuary but found much less in the freshwater areas than the 3 spined sticklebacks. Common goby were most abundant in the East India Dock Basin followed by Greenwich and Belvedere suggesting that they prefer middling salinities and soft substrates.

Atherinidae

Sand smelts (*Atherina presbyter*) are common inshore and estuarine fish of southern origin which shoal in shallow waters. Although they lay eggs onto marine algae, they have a largely mid-water existence, and so they are not frequently caught in bottom trawls. This species was dominant in the Victoria Dock Basin (75.1%). In other studies the species is said to lay eggs in thick algae substrates. Since these substrates are the common features of the Royal Dock Basins they provide a refuge for this species.

Osmeridae

The smelt species found in our waters are related to *salmon* and trout and are small bodied, marine coastal fish which enter rivers to breed in winter (Hutchinson and Hawkins, 1993). Smelt *Osmerus eperlanus* are relatively common in this survey, particularly in depths of 1 -2 m in brackish water. High numbers of smelt were recorded from Greenwich (11.9 %) and Belvedere (27.6% -through the five months sampling period) but low in Grays (0.8% through the seven months sampling period) the lowermost site and the upper reaches Battersea (1.2%), Hammersmith (0%) and Teddington (0%). They were also recorded in the Main Creek (44.9%), Darent Arm (0.7%), Crayford Arm (0.7%), East India (0.5%) and Queen Victoria Basins (16.0%). Smelt was the second most abundant species in the Queen Victoria Dock Basin after sand smelt; and although these two species co-exist they are not closely related. The sand smelt is more closely related to mullet (Maitland and Campbell 1992) whilst the smelt is more closely related to salmon (Hutchinson and Hawkins, 1993). Large population of ripe males and females smelts with eggs were collected in December and January in Greenwich and Belvedere. It appears that the females start preparing for spawning late in the winter period. By May, smelt had spawned and transparent larval stages were captured in these reaches as well as at Battersea.

4.7 Discussion

In South East England, the estuarine fish fauna of the Thames Estuary is an important resource for local markets. In the lower estuary and its entrance into the North Sea, the catches of the sea fishery, which targets mostly estuarine-related species, amounts of which vary from year to year according to sea fisheries regulation, is considerable (Rogers *et al.*, 1998). On the other hand, the estuarine environment in this region is also subject to heavy human pressure, with a population of 12 million and 40% of industries encompassing it (Environment Agency, 1997). The main Thames Estuary, its tributaries and Dock Basins, the human settlements they support and the fish they produce are illustrative of the strong interaction between people and the environment. Knowledge of the estuarine fish fauna, its geographic specificities and its natural driving forces, helps in the understanding and management of this resource. This chapter has summarised the major trends in estuarine fish biodiversity in the upper and middle estuary; species richness, composition and abundance of regional estuarine assemblages. The study indicates species rich environments, whose fauna depend on the river's hydrological regimes, the freshwater and seawater biogeographic regions and the seasons. The focus here is on areas between Teddington and Grays and some water courses associated with this stretch (Victoria and East India Dock Basins and the Dartford Creek). The comparison of estuarine ichthyofauna which follows is a synthesis of several local studies.

Preliminary surveys of the Thames Estuary were undertaken in 1960s and 1970s (HMSO, 1964; Wheeler, 1969b; Huddart and Arthur, 1971a, 1971b &1971c; Sedgwick and Arthur, 1976 and Sedgwick, 1978). These studies were used as a basis for more thorough surveys in the 1980s and 1990s (Colclough, 1992; Araujo, 1992; Chen, 1994; Araujo *et al* 1998; Araujo *et al* 1999; Colclough *et al* 1999; Colclough *et al* 2000; Colclough, 2001). These early studies showed that the young stages of commercially important fish, particularly sea bass, mullet, sole and plaice, could be found in inshore nursery grounds, but that there was no information on the size or extent of these populations. The subsequent surveys of the Thames Estuary between 1970 and 1989 (mentioned above) revealed the general extent of these nursery grounds, and identified those areas of the estuary which were particularly important for the survival and growth of young fish. More thorough surveys of these juvenile fish populations were undertaken throughout the Thames Estuary in subsequent years, and have continued to the present day. Annual indices of fish abundance, derived from these surveys, have been used during the assessment of the size of fish stocks, and information on the size and location of the most important nursery grounds has also been of value when considering potentially harmful developments along the estuary. In addition, data on the non-commercial species in the Thames Estuary have been used by the Environment Agency to monitor the presence in estuarine waters of infrequent migratory species, and to assess the diversity of these estuarine fish populations. Stations on the foreshore were sampled annually, during September, and a consistent dataset was produced. The Estuary was divided into 15 sectors on the basis of major geographical features such as salinity, substrate type, water quality and within these sectors, fixed fishing station positions were distributed within each of the Three Zones of the Estuaries (Environment Agency, 1997).

In the present study the population densities, relative abundances, and species diversity of the most common fish and their habitats have been described for the upper and mid Thames Estuary, Queen Victoria and East India Dock Basins and Dartford Creek. The following section summarises the major features of the distribution and relative abundance of small fish by family and by species. A total of 70650 individual fish were collected. The numbers for each of the ecological regions were: Zones 1 and 2 (53354); Zone 1 (26677); Zone 2 (8648); Queen Victoria Dock basin 11,384; East India Dock basin 21,076, and Dartford Creek 11,303). These 70,650 individuals were spread over 27 species Table 4.1 and 4.15. The communities varied according to the salinity gradients. The upper estuary and the two arms of Dartford Creek were inhabited mostly by freshwater species whilst the middle estuary, main trunk of the Dartford Creek, and the Dock basins by estuarine, marine and occasional freshwater species.

All species recorded in this study were also recorded by Huddart and Arthur (1971a and 1971b) Araujo (1992), Chen (1994), Colclough *et al* (1994), Colclough *et al* (1998 and 1999), and Araujo *et al* (1999) for the middle estuary, suggesting that estuarine recovery has largely stabilised. There are however species recorded by these earlier workers that were not recorded in this study probably because of the following reasons: 1) these workers included higher salinity sites; 2) larger nets were used and hence larger sample sizes obtained and 3) there were differences in the methods of collection. For example, Huddart and Arthur (1971a) collected three years data from power station cooling water screens and Araujo *et al.* (1998 and 1999) used 10 years power station screen data. In contrast this study used a single year of fish data collected by a 4mm knotless seine net which is primarily suitable for capturing juvenile fish. Species such as scud and haddock mentioned by Huddart and Arthur (1971b) as being frequent in the tideway at least in some periods of the year were recorded only occasionally between 1980 - 1989 by Araujo *et al* (1998) and there was no record of these species in the current study, probably because of the distance of the seaward most sampling site from the sea. Wheeler (1969a) cited twaite shad (*Alosa fallax*) and Allis shad (*Alosa alosa*) as entering the estuary in May to spawn in June - July. Neither was recorded by Araujo *et al.* (1998 & 1998) nor by this study.

The high abundance of flounder in the upper and middle estuary and the East India Dock basin reaffirms the continued role of the Thames Estuary as the nursery ground for this species. Huddart (1971), Wheeler (1979), Araujo *et al*, (1998 and 1999) and Colclough *et al*, (1999 and 2000) made similar observations on the abundance and seasonal distribution of flounder in the estuary. A high occurrence of smelt in the middle estuary and its scarcity in the upper estuary (< 0.5%) suggests that its life cycle distribution lies between the sea and the middle estuary, and does not support Hutchinson and Hawkins (1993)'s observations of the presence of large cohorts of the species in parts of the estuary as upstream as Teddington. The common goby seems to occupy the area between the middle and upper estuary through out its life circle. It was confirmed to be a true estuarine species. Five species contributed 89% of the total catch in the upper and middle Thames Estuary. Twenty three of the 26 species contributed only 11% of the number of fish caught. Roach and flounder together contributed 78% of the total catch. Overall this is consistent with the classical view of estuaries that although they are very biologically diverse, a few species make up the majority of their fish fauna (Wheeler, 1979, Sedgwick and Arthur, 1976, Araujo, 1992, Araujo *et al*, 1998 and 1999 and Colclough *et al*, 1998 and 1999).

A low frequency of occurrence of most middle estuary species contrasted with a greater constancy in the upper estuary. This reflected not only the greater variety of marine species but also their high seasonal occurrence. The marine species are present as a continuation or start of their life cycle compared with the residential nature of most freshwater species in the more stable conditions of the upper estuary.

Ten of the 12 most abundant fish species in the middle estuary are marine estuarine dependants entering the estuary in large numbers in variable periods. One of them, flounder uses the upper estuary as a nursery ground with juvenile recruits abundant in late spring and early summer. Araujo (1992) and Araujo *et al* (1998 and 1999) reported that the estuarine three-spined stickleback was the most abundant fish in the upper estuary during the summer, being more abundant in the middle estuary during the winter. This study did not find the same results. In this study flounder (mostly post larvae) and roach followed by other cyprinid teleosts dominated the upper estuary in summer.

In the middle estuary, other estuarine dependant species namely: common goby, sea bass, smelt, dab and place dominated the community, although the three-spine stickleback was also abundant.

In general, fish of the families Pleuronectidae, Gasterosteidae, Serranidae, Gobiidae, Osmeridae and Atherinidae were the most abundant in the brackish water areas. In the Dartford Creek system, and the dock basins, there was a numeric dominance of the families Pleuronectidae, Osmeridae, and Gobiidae with reduced occurrence of individuals from other families. These observations differed from the observations made in the upper estuary and at sites of additional habitats with low salinities, (upper zones of the Crayford and Darent arms of the Dartford Creek system). Within these low salinity tidal habitats the families Cyprinidae, Pleuronectidae and Percidae dominated and there were reduced numbers of fishes from the families Gasterosteidae, Serranidae, and Osmeridae. In the Queen Victoria Dock basin which is separated from the main river for most of the year, Atherinidae were abundant, Osmeridae were relatively abundant and the family Serranidae was present but sparse. The abundance of Pleuronectidae, Osmeridae, Gobiidae and Atherinidae in the brackish water zone of the main river was previously observed by Wheeler (1979), Araujo (1992), Chen (1994), Colclough *et al* (1999), Araujo *et al* (1998 and 1999) Colclough *et al* (1999 and 2000). Whilst estimating the population of fish in the upper and middle Thames Estuary these workers observed that Mugilidae and Clupeidae were only present in the middle estuary at high tide, when there was a gradual increase in salinity. In the present study, although the specific diversity is high, most of the species are present in the estuary in small numbers, which is a characteristic of the estuarine environment (Remane and Schlieper (1971), Kennish (1990) and Power *et al* (2002).

The proportionality observed in the occurrence of 0+ and 1+ fish in the upper and middle Estuary is similar to that observed by Araujo *et al* (1999) in the upper Thames Estuary. The larger occurrence of 1+ individuals observed by Colclough *et al* (1999 and 2000) at the same sites can be attributed to differences in the net selectivity. The current study used a 25m x 4mm knotless fry net, whereas Colclough *et al* (1999 and 2000) used a 10 mm mesh. Clearly, the use of two nets with different meshes and dimensions would have given a better overall representation of the fish present in the study area.

There is a periodic invasion of the shallow areas of the upper and middle estuary, Dartford Creek system and the East India Dock basin by offspring of species of fish that spawn in the North Sea as previously observed by Wheeler (1979) Rogers *et al* (1998). These species are transients, in the sense that they are only temporary residents of the habitat, although, in seasonal terms, they actually dominate the community, with population oscillations due to immigration and emigration (Wheeler, 1979; Araujo *et al.,* 1998 and 1999; and Colclough *et al.,* 1999 and 2000).

The seasonal variations in abundance and in diversity observed in the tidal Thames demonstrate the alternation in the migration process. The largest number of both individuals and species in the spring and summer months was caused by the immigration of juvenile forms into the tidal Thames, while the reduction in the autumn and winter corresponds to emigration of fish to other habitats (Wheeler, 1979; Rogers *et al,* 1998; Araujo *et al,* 1999). Estuaries, coastal bays and shallow habitats are systems that work as important areas for breeding of fish, mainly in the spring and in the summer, when the occupation indexes and the primary and secondary productions are larger (Barnes, 1994 and Rogers *et al,* 1998). The seasonal coincidence of peaks in abundance of fish suggests that food availability can be the main factor influencing the nursery function of these nursery areas.

The high abundance of juvenile marine fish in the tidal Thames confirms the importance of these habitats as growth and feeding areas. Several families comprising Pleuronectidae, Osmeridae, Gobiidae, Anguillidae and Serranidae, common in regional commercial catches (Rogers *et al* (1998) are present in the estuary in the stages that precede the recruitment to the adult population. The results of this study show that the tidal Thames is equally important for the species resident in the estuaries and for the occasional visitors as well as for reproduction of some species.

Smelt, described previously by Wheeler (1979) and Hutchinson and Hawkins (1993) as one of the most important fishery resources in the middle estuary in the last century was confirmed as a truly estuarine species, with high occurrence in the middle estuary, the brackish East India Dock Basin and the Dartford Creek system appearing to be well distributed in the estuarine environments. Historically, in other British estuaries this species is absent or rare.

A number of species appear to be more common now in the upper and middle Thames Estuary than at the time of Sedgwick's (1978) study. For example, both Huddart and Arthur (1971) and Sedgwick (1978) recorded sea bass as occasional in the tideway while this species ranked eighth in abundance in the middle estuary in the 1980s (1980 - 1989) Araujo *et al* 1998. In this study sea bass ranked second in the middle estuary making up 16.0% of the total catch after flounder (37%). Changes in the relative abundances of the most numerous species occurred indicating changes in community structure. However, time of sampling, different sampling methods, sample sizes, number of sampling sites and sampling distances from the sea also influence the results of fish community investigations. Unless the same sites are sampled by the different field workers at the same time using the same nets and effort comparisons of data (as mentioned earlier) can be a contentious issue.

As far as the dominant species are concerned, the fish composition pattern in the mid Thames estuary conforms broadly to that of estuaries of in South-western UK namely the Severn and the Tamar and the Scottish Ythan (Rogers *et al* 1998). The large contributions made by a limited number of species in this study (top 5 species = 89%) resembles the situation reported for estuaries in various parts of the northern hemisphere including the Thames, Wheeler (1979) and Wolff *et al* (1981 & 1983) Araujo *et al* (1998 and 1999), Colclough *et al* (1999 and 2000). However, comparisons between estuaries are difficult because sampling sites may vary in their distances from the sea, resulting in obvious differences in fish composition and relative abundances.

The distribution and abundances of different species demonstrate clearly the zonational aspect of the estuarine fish fauna. The most upstream site, Teddington, is dominated by roach and other freshwater species; Hammersmith is similar but had large numbers of 0+ flounder in May and June. Battersea also had flounder but the freshwater fish component was much reduced and more marine species were present. Greenwich, Belvedere and Grays were brackish in nature although surprisingly, significant numbers of freshwater species had penetrated Greenwich and Belvedere. One feature of this distribution pattern was the fact that several freshwater species survived right down to Grays and on the other hand dab and plaice have been recorded as far up river as Hammersmith. One must assume that the salinity tolerances of these teleosts fishes are very wide in terms of lethality. However, it may well be that at the extremes of their range the various fish species may be physiologically stressed and may have to expend much energy in overcoming the salinity gradients that they face (Jobling, 1995). If the various species can tolerate wide salinities ranges/gradients as demonstrated in this survey alternative reasons must be sought for the different relative success of species in particular zones. There are a number of possibilities. For example, suitable breeding conditions in terms of flow and substrate as well as salinity may mean that certain species originated in one particular area or move from adjacent tributaries and creeks into the main river at particular points. Evidence from this study gives several pointers to this direction. Very small roach fry were extremely abundant in the early summer at Teddington and it seems obvious that this is a major breeding area as one would expect from the nature of the habitat with stony substrates and marginal vegetation. As they were progressively less abundant downstream it seems likely that these populations may be the result of limited breeding success or downstream spread from the Teddington area.

On the other hand dab and plaice spawn at sea and the young migrate into estuaries where they usually stay for about 2 years (Wheeler, 1979). The focus for their population is thus the seaward end of the estuary where they are far more abundant than upstream. At least 3 species, sea bass, flounder and smelt, breed successfully in the estuary and require such an environment for successful spawning. In this study the breeding zone of flounders centred on Hammersmith reach where the fry were the predominant fish in samples during the late spring. Previous reports of smelt spawning as far upstream as Wandsworth by Hutchinson and Hawkins (1993) have not been fully confirmed in this study. The evidence from captures of very small smelt fry suggests that their main breeding ground is in the middle estuary at Greenwich and Belvedere reaches. A limited number of larval and post larval stages were captured in Battersea.

Another possible factor influencing the distribution and abundance of species is the harsh winter conditions in the estuary with faster flows in the main river. Certainly the freshwater fish fry that were dominant in the upper estuary and present in the middle estuary during the summer essentially disappeared in winter months although 1+ fish of most species continued to be caught throughout the year in small numbers. One suggestion that was raised in the introduction of this thesis was the possibility that creeks, docks and tributaries could have a significant role as refugia for fish during unfavourable conditions in the main estuary. Refugia could act as areas of respite from either harsh physical or chemical conditions. They could also provide feeding grounds if food becomes scarce in the main river. The latter will form the basis of discussion in following sections.

There was a marked difference in fish species assemblages between the Royal Victoria Dock and the East India Dock basins. The very high abundance of sand smelt (75.1%), followed by smelt (16.0%) in the Queen Victoria Dock basin suggests that conditions are favourable in the basin for these species and that there is very little competition or predation against them. The East India Dock Basin had a totally different community structure from that of the Victoria Dock Basin but very similar species composition and community structure with the main river (mid estuary). This is due to the influx of tidal water with the Greenwich meander. Secondly, although the East India Dock Basin is small it has a much protected heterogeneous habitat. The very high presence of three-spined stickleback (46.5%) and common goby (24.6%) in the basin is due to the sheltered nature of the environment and the presence of marsh vegetation and the *Phragmites* reed bed which act as a cover against predatory birds and fish species. In the East India Dock environment, chironomids, oligochaetes and polychaete worms which are the main diet of flounder, common goby and the three-spined stickleback are abundant.

The Dartford creek system yielded lower numbers of fish compared to the rest of the water ways surveyed despite the extensive surveys carried out in that estuarine system by the Environment Agency. The dominant species was flounder (51.4%) in their post larval stages followed by common goby (16.6%), smelt (14.1%) and roach (9.68%). The reason for the low numbers is probably due to the fact that, firstly, despite the existence of physically unspoilt mashes in the creek system, the main trunk of the Creek dries up at low water. Secondly the presence of the flood barrier restricts the ingress of many marine species from the main river. Thirdly the water quality of the two arms of the creek was poor due to intermittent pollution by leachates from the Erith landfill, possibly Welcome Foundation industrial discharges, and surface water sewers in the Darent. During the survey period, water quality of the Darent and Crayford Arms varied between class 2B and 3 of the River Quality Classification system, (Ramoeli, 1994 and Thomas, 1998). In this water quality classification system, class 2B should be capable of supporting reasonably good coarse fisheries whereas class 3 is not expected to support a viable fishery.

The fish fauna of the main arm of the Dartford Creek was very similar to that of the adjacent main river sites of Belvedere and Grays whilst the Cray and Darent Arms were more typically low salinity areas and have species assemblages similar to that of the upper estuary (Tables 4.3 to 4.8 and 4.16). In terms of a refuge it is unlikely that freshwater fish fry from the upper estuary of the main estuary would find a refuge so far downstream. However, one species, chub, was lifted in the main arm of Dartford Creek but not in the low salinity upstream, suggesting that the species had entered the creek through the brackish water zone of the mid estuary, or had dropped down from above the Darent tidal weir.

The docks were particularly interesting in terms of possible refugia. They offer calm, no/low flow conditions in winter and might reasonably be expected to be a safe haven for fish moving out from the main stream. The two docks studied appear quite different with respect to their habitats. Victoria Dock is essentially isolated from the main river and only occasionally is there opportunity for the ingress and egress of fish. It has a rather specialised community structure comprising mainly sand smelt which dominated the catches. Smelt were also abundant as were sticklebacks.

The East India Dock Basin has higher habitat heterogeneity but it too a dominant species which seem to particularly thrive in this habitat, the sand goby. This basin has open access to the main river and showed ingress of smelt and flounders during the spawning season and an egress of freshwater fish during the winter. There was no real evidence that fish fry congregate in the dock during the winter months. However, caution must be exercised in interpreting the seasonal distribution pattern of fish in the dock basins, especially the Royal Docks which have a very restricted access for the egress of migratory fish out of the basin. The question to be answered in future research is: if fish cannot leave the basin during the cold season because of the restricted exit route, where are they in the winter months? The answer to this question may lie in the differential water temperatures characteristics of the waters of the basins. The Royal Docks are well known for their perennial thermoclines because of their great depths in excess of 60 ft, (Royal Docks Management Authority, 2004). The temperature of the water in the upper layers closely reflects the ambient air temperature, but generally only in the periods between May to early October does the temperature exceed 15 ^{0}C. It is quite possible that juvenile fish migrate into warmer waters of the basin in winter avoiding the colder margins where these surveys were carried out.

Queen Victoria Dock basin also displayed low fish species diversity but high concentration or dominance of one species (Table 4.18) namely: sand smelt *Atherina presbyter.* This species contributes 75.1% of the fish population sampled over the period of one year. The smelt *Osmerus eperlanus* is the second most abundant species. Both species are typically marine species. The occurrences of high populations of amphipods, copepods, decapods (prawns), and isopods, which act as readily available food sources in the basin, plus the occurrence of clean water, are environmental conditions and resources which facilitate the growth in the population of these two species. As mentioned in the macroinvertebrate studies section it is worth reiterating that the water quality of the waters of the Royal Dock Basins complies with the requirements of Directive 78/659/EEC, (Royal Docks Management Authority, 2004) meaning that this water is suitable for potable supply if desalinised and suitable for all other abstractions and fisheries and of high amenity value. Inputs of freshwater from rain contribute to the basin water volumes and this is believed to influence the salinity of the water in the dock basins. For example there was high mortality of sea bass (*Dicentrarchus labrax*), a marine fish species in the dock basin in the spring of 2000. The Environment Agency, who was called to investigate the cause of the mortality, speculated in an internal unpublished memo that this incident had been caused by osmotic stress induced by reduced salinity due to high rainfall and high freshwater inputs into the dock basins that year. It is therefore possible that the current populations of sand smelt and smelt are sustained by low predation and competition. This speculation has not been backed up by long-term data, but it raises the awareness as to the sensitive or fragile nature of these manmade environments. Unfortunately no detailed study has quantified the effect of all the causes of periodic fish mortality in Royal basins. Thus it is not known what limits the numbers of fish in these environments.

Periods of droughts have also been recorded in the mid 1990s, but their impact on the community structure is unknown.

Similarities between the Darent and Crayford arms and the upper Thames Estuary are very apparent from this study's fish results. Fifteen species of freshwater and estuarine fish were captured in the Dartford Creek: Flounder (51.4%), common goby (16.6%), smelt (14.1%), eels (1.7%) and occurred widely throughout the River Cray (Dartford creek system). Typically freshwater species [roach (9.7%), dace (1.2%) and perch (<1%)] were limited to the two arms of the creek whilst some of the marine species [herring (<1%), sprat (3.29%) and sea bass (<1%)] were only taken from the Main Creek. The two arms of the creek (Crayford and River Darent) like the upper Thames Estuary are low salinity sites. This is reflected in their similarity in species assemblages dominated by roach, 0+ flounders, perch and dace. However, the two arms are small streams compared to the upper Thames estuary. They are shallower and narrower; hence although their substrates are very similar, the arms of the Dartford creek are less complex in terms of habitat structure and are also more vulnerable to intermittent pollution.

The results show that rich and diverse fish communities are associated with the Thames Estuary and its associated water systems. Dartford Creek, the estuary and the East India basin are important nursery grounds for a broad range of freshwater and estuarine species. The extensive reed beds of the Dartford creek provide a marginal habitat rare in the Thames Estuary but with low fish diversity due to poor water quality and other anthropogenic disturbances including barrages.

Many marine fishes depend on estuaries during part of their life cycle. Besides these marine fish, the estuarine ichthyofauna also encompasses species that spend their entire life in the estuary. A mosaic of habitats, including marsh, tidal creeks, docks, tributaries and the water column, offer several food sources, protection against strong water flow, besides other favourable conditions for growth and survival of the initial stages of the fish life cycles. The use of the Thames Estuary and its associated water systems as nurseries is crucial for the survival of many species, including several that are important in fishing, e.g. sea bass, flounder, smelt and eel (Wheeler 1979; Rogers *et al* 1998; Araujo *et al* 1998 & 1999).

The method used to capture fish from the environments discussed above has its advantages and pitfalls. A single fry seine net was used throughout the survey programme. Unpublished fish data for the Dartford Creek were supplied by the Environment Agency and was obtained by a different net - a 10 mm trawl net. This is a source of data variation.

Seine netting in the Thames estuary was hardly straightforward. The substrate had a huge influence on the net retrieval and in places caused a lot of problems with regards to total net weights. The ideal substrate for seine netting consists of solid clean clay but this rarely exists along the Thames Estuary. However, the upper Thames Estuary with clean gravel substrates provided good netting sites. On some occasions, in the mid Thames Estuary, silt needed to be removed from the net while pulling it in. The net was tightened and the leads were quickly lifted then dropped resulting in a 'dumping' of excess material. This did run the risk of fish escape, but if the net was of a weight exceeding the retrieval capability there was no other option. More commonly the silt was pulled to the bank.

Snags were an obvious problem and resulted in net damage. Again the net was usually removed with careful manipulation of the leads. Islands caused a lot of problems in rocky foreshores e.g. Belvedere, but the well organised team laid smaller stop nets hence splitting the reach into sections. This procedure did require experience. Holes in the river bed can hold large quantities of fish as observed in Grays but although this was of a deep nature the problem disturbing the fish out of the holes before net pulling.

Weed in large quantities made netting difficult in Grays where there was a lot of seaweed and sea grass submerged in the water most of the time. Sea weed and sea grass were the worst offenders as they entangled and then rolled the net top to bottom. This problem was managed by first completing the 'arc' and then manipulating the net from the back and making sure that it did not roll top to bottom. Finally, large vertical shelves around the river margin tended to lift lead lines to such an extent that in several occasions all fish escaped before landing. Time and patience was the only solution with a very slow net retrieval being the best option employed.

Fish species had different reactions to a seine net. Bream shoaled in the centre and followed the net in until they were caught easily. Roach and dace also shoaled, but tended to find escape through the net mesh. Sea bass, being more aggressive, buried underneath the leads and if escape was successful became increasing harder to catch in continued netting. In Grays, in summer months, large sea bass went for the easier option of jumping the float line. Mullet tended to jump out of the net as well. There was always the possibility of losing a few fishes but lifting majority.

In conclusion three aspects of the fish results have been broadly discussed in the fish studies section. The first aspect is the marked variability in species numbers within and between localities and seasons. The second aspect is the variability in the numbers of individuals i.e. population sizes between and within localities and seasons. The third aspect of the fish study is the variability in the composition of species recorded between sites i.e. the variability in community structure. A further aspect of discussion is the relationship between fish distribution, abundance and community structure with the physical environment and the availability of food. This fourth aspect is discussed in chapter 5. Studies on the distribution of species within the main river system of the middle and upper Thames Estuary confirm that the river has largely recovered from the severe pollution of the 1950-1970's. Several species known to be sensitive to pollution such as smelt and sea bass have been found in the estuary at all times of the year Araujo *et al* (1998 and 1999), Colclough *et al* (1998 and 1999). Although the distribution of species, particularly 0+ fish, vary considerably seasonally, it appears much more likely that these changes are related to life-history stages and migration rather than response to pollution gradients.

Chapter 5

ONTOGENETIC, SPATIAL AND TEMPORAL ANALYSIS OF THE GUT CONTENTS OF THE 12 MOST COMMON FISH SPECIES IN THE UPPER AND MIDDLE THAMES ETUARY

5.1 Abstract

The stomach contents of 720 individuals belonging to twelve fish species were examined in order to investigate ontogenetic, seasonal and spatial changes in feeding strategy in the Upper and Middle Thames Estuary (Zones 1 and 2 respectively). 0+ year class consumed a smaller range of food items than the 1+. 1+ year classes consumed a reduced range of food items in winter than in the summer. The more generalist feeders comprising perch, eel, smelt, sea bass and three-spine stickleback consumed a greater range of food items. There were variations in food availability and species feeding selectivity (β). Diet overlap values, between all species as measured using Schoener's index (α), were very high regardless of ontogeny, seasonal changes or the spatial distribution of the individuals and, ranged from 0.89-1.00. Species tendency to be more generalist (diet width, δ) was lowest during ontogeny and winter and was highest in the summer.

5.2 Introduction

In this chapter the diet of fish species in the Thames Estuary is described. Previous studies specifically designed to examine the diets of fish in the Thames Estuary have been limited to single or a few species. For example, the diet of flounder, chiefly in the mid Thames Estuary were examined by Huddart (1971) followed by Sedgwick (1978), Jarrah (1992) and Chen (1994). Studies of the diet of this fish in other British estuaries have been carried out by several workers, for example Ascroft (1900); Hartley (1940a); Moore and Moore (1976); Kartar (1977); Parsons (1978); Summers (1979 and 1980); Beaumont and Mann (1984). In Hartley's (1940a) study, small crustaceans and polychaete worms were found to be the main food for small fishes and the shore crab, *Carcinus maenas* for larger flounders from the Tamar and Lynher estuaries. In Huddart's (1971a) studies small crustaceans and gastropods were found to be the main food for the majority of flounders present in the tidal Thames at the time. Hutchinson and Hawkins (1993) examined the diets of smelt in the Thames Estuary and the River Cray. In most of these studies, except in Chen's (1994) study of the diet of the Thames Tideway flounder, little or no attention was given to ontogenetic, temporal and spatial differences in diet. Thus, in the present investigation detailed attention is given to the diets of two age groups, namely 0+ and 1+ (1+ = 1+ and >1+) individuals of the 12 species that make up 96% of the total catch of fish in the upper and mid Thames Estuary for both summer and winter seasons namely: the fresh water species perch, bream, dace and roach and the brackish water species common goby, gudgeon, eel, flounder, three-spined stickleback, smelt, sea bass and mullet. Eel could be in any of the classifications. This approach broadens the knowledge of the diet of the present fish assemblages in the tidal Thames. The approach also broadens knowledge of the ecology of the river with respect to the resources available in a stressed natural habitat. The following sections give brief statements of the general aims and methodology adapted in this study and review earlier studies for gut contents carried out in the Thames and other British estuaries.

5.2.1 Aims and objectives

Fish gut contents were examined to determine: a) if different fish species consumed the same prey/food types b) if feeding shifts occurred between ontogenetic stages c) if feeding shifts occurred between the upper and middle estuary and d) if feeding shifts occurred between winter and summer seasons. The specific objectives of the gut contents study were as follows:

1. To capture and preserve adequate samples of fish species listed above from Zones 1 and 2 of the Thames estuary in the summer and winter seasons for gut contents analysis.
2. To identify the main diets of fish from their gut contents.
3. To construct diet tables from the food items identified from the gut contents.
4. To categorise food items into groups.
5. To carry out analysis of diet structure. The diet matrices comprise diet width, diet overlap and selectivity index.
6. To analyse by simple proportion (percentages) differences in diet in:
   (a). in 0+ and 1+ year classes;
   (b). for fish feeding in Zone 1 (the upper estuary) and 2 (the middle estuary);
   (c). for fish feeding in winter and summer seasons.

5.3 Methodology

5.3.1 The Fish samples: species selected for analysis and their residential status in the tideway

Table 5.1 shows the 12 fish species selected and their residential status in the tideway. The reaches chosen for the selection of fish for gut analysis were the same reaches chosen for the earlier fish and macroinvertebrate studies. The invertebrate samples served as a reference collection of invertebrates from the estuarine zone to aid in prey identification. Several species utilise both Zone 1 and 2 and of these, 12 important species were identified and selected.

Table 5.1 Fish species selected for gut contents examination and their residential status in Zones 1 and 2 of the Thames Estuary

Species	Common name	Resident species in zone 1	Resident species in zone 2	Transient species in zone 1	Transient species in zone 2	Transient species in the estuary
Perca fluviatilis	Perch	X			X	
Leuciscus leuciscus	Dace	X			X	
Rutilus rutilus	Roach	X			X	
Pomatoschistus microps	Common goby*	X	X			
Gobio gobio	Gudgeon	X			X	
Anguilla anguilla	Eel			X	X	X
Abramis brama	Bream	X			X	
Platichthys flesus	Flounder			X	X	X
Gasterosteus aculeatus	3 s. stickleback	X*	X			
Dicentrarchus labrax	Sea bass		X	X		
Osmerus eperlanus	Smelt		X	X		
Liza ramada	Mullet			X	X	X

* present throughout the upper and mid estuary

Species that reached the highest occurrence frequencies year round were selected to analyse diet variations in Zones 1 and 2 between winter and summer. Another 14 species were part of this fish community. Because some of them did not appear in sufficient numbers and others were occasional species with low population densities during the whole year, they were excluded from the analysis.

From the 12 species selected, 5 species originate from upstream of the low salinity Zone 1 (perch, roach, dace, gudgeon and bream) and are abundant in Zone 1 but also penetrate Zone 2 to a limited extent; 5 species originate from the high salinity Zone 3 and sea beyond but are abundant in Zone 2 and penetrate to varying extents into Zone1 (smelt, sea bass, eel, flounder and mullet) whilst 2 species (common goby and three-spined sticklebacks) could be described as universally resident species being well represented in all zones of the estuary. Fishes of the 0+ and 1+ age groups were collected in the summer and winter months of 2001 and 2002 with a seine net in Zone 1 (Teddington, Hammersmith, Battersea) and Zone 2 (Greenwich, Belvedere and Grays). Fish samples were immediately preserved in 4% formalin to prevent deterioration of gut contents. The 12 species chosen for gut analysis were sufficiently common to provide samples of 10 individuals of each age group from both zones in summer. In winter only the 1+ age group could be collected in sufficient numbers. However, the smelt examined for Hammersmith were the 2000 batch since no smelt were captured in this site in 2001; but the rest of 11 fish species samples were selected from 2001 winter and summer catches.

Table 5.2 shows the number of fish examined for gut contents in each age class. (The age classes of sampled fish were determined by the use of age-length keys and circuli analysis as described in Chapter 3). Eels were aged using the Environment Agency size/age data (Colclough, 2000)

Table 5.2 The total number of fish examined for each species and age class from Zones 1 and 2. The method of age analyses is indicated.

			Numbers of fish in each age class				
Species	AL K	circuli	0+	1+	2+	3+	>3+
perch	X	X	20	20	12	8	0
dace	X	X	20	20	16	4	0
roach	X	X	20	32	8	0	0
common goby	X		20	36	4	0	0
gudgeon	X		20	28	8	4	0
eel		X	20	38	2	0	0
bream	X	X	20	24	10	4	2
flounder	X		20	30	6	4	0
3-s' stickleback	X	X	20	40	0	0	0
smelt	X	X	20	21	5	12	2
sea bass	X	X	20	22	18	0	0
mullet	X	X	20	5	32	3	0

ALK = Age-length keys

5.3.2 Gut content analysis

Some authors have described gut sampling of living fish using stomach pumps (Culp *et al*, 1988). However this method is only available for large fish with discrete stomachs. A more universally applicable method is removing the gut and gut contents from fish by dissection (Hyslop, 1980 and Bowen, 1983) and this method was adapted in this study as described below.

Laboratory procedure for removing and identifying gut contents

Using a dissecting microscope, the gut contents of fish from each of the 12 species selected were examined.

1. Using appropriately sized scalpel, a longitudinal cut was made on the ventral side of the fish from just behind the isthmus of the gills posteriorly to the anal fin. Then two transverse cuts were made at each end of the first cut to open the coelom and expose the viscera.
2. Using a sharp-pointed surgical scissors, the oesophagus, the last few millimetres of the intestine and the mesentery at the dorsal point of its attachment were severed. This allowed the visceral mass to be lifted out of the coelom for more detailed examination and manipulation.

3. The digestive tract was separated from the other visceral organs. The stomach or foregut was severed from the rest of the gut.
4. The stomach or foregut segment was opened carefully by making a shallow slit lengthwise with fine scissors (ensuring that the prey was not cut). For piscivores, whole prey items were lifted directly and carefully from the stomach. For smaller prey, the slit segment was held with forceps over a Petri dish and the contents washed out with drops of water from a pipette. The gut mucosa extruded was noted to ensure that it is not mistaken for part of the diet (Bowen 1983)
5. For each individual fish, prey items were sorted, identified and counted. The data for each fish was recorded in a fish species and food items matrix (Appendix 5, Tables 1 to 6). Some studies, e.g. Bowen (1983) suggests that the total percentage of the total volume of the stomach contents made up of each prey item should be estimated especially if detritus and algae are included in the diet. The present study did not do this as the alternative method chosen sufficiently satisfies the gut content analysis. If food items were disarticulated or partially digested, a characteristic part (best part found once per prey (e.g. parts of the exoskeleton, carapace, legs, scales etc was counted as one food item). For amorphous foods taken in bites (for e.g. detritus or silt) the items were stirred in distilled water to aid identification. Organic materials were distinguished from mineral components such as clay particles by colour and feel.

Grouping gut contents

To aid and to simplify the mathematical analysis of the fish diet the stomach contents were grouped into three broad categories:

i. Fish,
ii. Crustacea
iii. Other

The group 'Fish' constituted common fish fry found in the estuary. The group 'Crustacea' constituted a variety of species from this class of the phylum Arthropoda; the group 'Other' constituted the tiny worms found in muddy substrates and an assortment of unrelated items of both benthic and terrestrial origin. These groups are described further in the following sections.

5.3.3 Statistical Analysis of gut data

The following statistical methods were used to analyse the gut content data:

5.3.4 Diet/food Analysis

Analysis of diet structure is a useful way of examining patterns of feeding in a habitat and drawing inferences about the magnitude and possible competition, (Schoener, 1970)

5.3.5 Calculating the frequency of occurrence of foods

This was the proportion of fish that contained a given food type. It was the fastest approach by which to quantitatively analyse the fish diets, because only the presence or absence of a food item needed to be recorded. This analysis indicated the extent to which fish in the samples functioned as a single feeding unit (i.e. high frequencies of occurrence for food types used by many individuals; low frequencies for most foods when individual fish specialise). Incidental ingestion of some items (e.g., sediments or detritus by benthivorous fish) also resulted in their occurrence at high frequency. Alternatively, the occurrence of even a single prey item in a stomach was recorded as positive, even if it was a small fragment of the organism. Consequently this study provided information on diet range rather than relative abundance of different food items in the diet.

The occurrence of a food items was calculated as follows:

$Oi = (ni/N)$ where:

Oi = the occurrence of food item i

ni = number of fish that contains food item i

N = total number of fish i.e. 10

5.3.6 Diet width

Diet width (δ) was used to indicate the range of resource use by a single species along the environmental gradients (Zones 1 and 2) and was defined as:

$\delta = 1/(\Sigma p_i^2)$ where

p = is the proportion of records for the species in each category (i) of a particular food type. The value of δ varies from 1.0 to n where n is the number of categories of food items. Diet width is literally the range of food items consumed by a given species.

5.3.7 Feeding Selectivity

To compute feeding selectivity (β) for the 0+, and 1+ age groups for each zone and season, the Lawlor (1980) Selectivity index (β), i.e., the ratio of the number of food types between stomach of one particular species and stomachs of all species. Feeding selectivity (β) was computed using the Lawlor index which is defined as:

$\beta = X_i/\Sigma i$ where

X_i = the number of individuals of a species consuming item i and Σi = number of individuals of all species containing item i in a season or zone. According to Winemiller (1989), in this procedure the fish is regarded as being an estimator of the available resource in the environment.

In this study the number of food types in the diet spectrum represent the number of fish containing item i (maximum 10) and hence represent the relative quantity of item i.

5.3.8 Diet overlap

To compute diet overlap between species the Schoener (1970) index (α) that varies between 0 (lack of diet overlap) and 1 (total diet overlap) was computed. For each species the selectivity index value was substituted for the proportion of each food type in the original formula, (Winemiller, 1989; Winemiller and Kelso-Winemiller, 1996), so that it could be interpreted as indicative of food types availability,

$\alpha = 1-0.5\{\Sigma^{n}_{i=1}[pX_i\text{-}pY_i]$ where

pX_i, pY_i = food electivity for x and y species; n = total number of resources

5.3.9 Cluster analysis of fish consumers and food items

Cluster Analysis is a multivariate analysis technique that seeks to organise information about variables so that relatively homogeneous groups, or "clusters," can be formed. The clusters formed with this family of methods should be highly internally homogenous (members are similar to one another) and highly externally heterogeneous (members of one cluster are not like members of other clusters (Aldenderfer and Blashenfield, 1984).

Although cluster analysis is relatively simple, and can use a variety of input data, it is a relatively new technique and is not supported by a comprehensive body of statistical literature. So, most of the guidelines for using cluster analysis are rules of thumb and some authors caution that researchers should use cluster analysis carefully in order to avoid the pitfall of over-interpreting the results, (e.g. Kim, Mueller and Charles, 1978 and Hair, 1992).

The main outcome of a cluster analysis is a dendrogram, which is also called a tree diagram. Clustering techniques have been applied to a wide variety of research problems. Gauch (1982) provides an excellent summary of the published studies reporting the results of cluster analyses

For the purpose of this study, gut contents results and fish consumers were clustered to derive associations between consumer species in terns of food habits and food items were clustered to explore the association of the various food items to the various consumer groups.

5.4 Results

5.4.1 Food items identified from the fish guts

The following food items were identified from the guts of 12 species of fish from the upper and mid Thames Estuary: branchiopods, crangonids, gammarids, amphipods, copepods, isopods, cyprid larvae, terrestrial insects, detritus, water weeds, algae, silt, oligochaetes, chironomids, polychaetes, gastropods, and fish fry (fry of perch, smelt, bleak, roach, mullet, flounder, dace, goby, stickleback and sea bass).

Food Groups

Food items were aggregated to give 3 groups as follows:

'Fish'

The fry of fish appear in large numbers in the stomachs of the predatory fish species on the Thames Estuary. The species of fish recorded in the diet depends on the species of predator, the season and the location. Perch, sea bass, smelt and eel devour fish fry and young fish including their own species in large numbers in early spring and throughout the summer months. This is the spawning and nursery period when a large number of the fry of each species are produced in the Thames estuary to take advantage of the high temperatures and abundant food sources available.

'Crustacea'

Foodstuffs in this category are the most obvious in the stomach contents of fish that prey on them. They are eaten by every species of fish in the Estuary. Wheeler (1985) published quantitative data that show that Crustacea are the most important food group (with gammarids the dominant members) for fish in the Thames Estuary. The data presented here partly support Wheeler's claim in that members of this food category (branchiopods and amphipods) form the food items for the early life stages of all the fish examined. The main crustacean prey species are: branchiopods, crangonids, gammarids, amphipods, cyprid larvae, copepods, and isopods. They occur in the entire estuarine habitat, from the supralittoral zone to the deep. It is their abundance, diversity in forms and ease of consumption that probably make them very popular food items in the food spectrum.

'Other'

This group is called 'Other' because it contains very important food items of unrelated forms. The only thing that they have in common is the benthic nature of their existence apart from the item terrestrial insects. Members of this food group include: oligochaetes, polychaetes, chironomids larvae (and pupae), terrestrial insects, waterweeds, algae, detritus and silt.

Oligochaeta

Oligochaeta is a heterogeneous group consisting primarily of tubifex worms but in this study includes other worms including pot worms (Enchytraeidae) and leeches (Hirudinae) which are difficult to distinguish from each other in states of partial digestion. The group 'Oligochaetes' in this study thus consists of small wormlike animals which live in the sediments. These worms are omnipresent but known to occur in huge numbers in creek mudflats and in areas close to sewage works outfalls where there is a lot of particulate and dissolved organic matter.

Polychaeta

Polychaeta are a large assemblage of diverse segmented worms found in the soft sediments (mud) habitats of the estuary. The most abundant family in the Thames is the Nereidae, which contain a number of species.

Gastropoda

Gastropoda listed as food items are mostly snails less than 1 cm long found everywhere in the estuary. Limpets are also included in this category.

Chironomidae

Chironomidae commonly called blood-worms are fly larvae and pupae, which occur, in large numbers in the brackish waters of the mid-estuary. They are also present in large numbers in weeds in the fresh waters of Teddington.

Detritus

Detritus is an important dietary component and needs careful definition. Because it tends to be amorphous it can easily be overlooked. Previous researchers on the Thames Estuary have not given detritus the importance that it deserves as a major food item of fish. Fish diet spectra in this study, based on age, temporal, and spatial analysis show the major importance of detritus as a food source to fish in the Thames Estuary.

Elsewhere detritus has been reported to relate to high fishery production, (Mann, 1972 and 1995; Nixon,1980 & 1982; Valiela, 1984 and Misch and Gosselink, 1986). Detritus in coastal systems has been defined in a variety of ways, (Darnell, 1967; Wetzel *et al* 1972). Mann (1972) defined detritus more broadly, as all non-living organic matter with its associated microbial community. Mann's definition is adopted here for the pragmatic reason that it is unrealistic and difficult for either a scientist or consumer organism to distinguish between non-living organic matter and its associated microbiota.

Detritus is added to the Thames Estuary via direct input to the water column and surface sediments. The two largest sewage works in the country (Crossness and Becton) discharge their treated sewage effluent directly to the Estuary. The input of detritus also occurs via allochthonous inputs from riverine, marine, and terrestrial sources Many of these inputs are anthropogenic, or from the breakdown of allochthonous primary production in the form of macrophytes leaves, phytoplankton, benthic algae etc. Detritus is also formed from the decay of autochthonous primary and secondary production, (Turner and Johnson 1973).

A close look at the diet spectra reveals that many fish species consume organic detritus, especially in the guts of younger fish consumers. Darnell (1967) states that the food value of detritus is not the dead organic matter substrate, but in fact, is the microbial community living on it. According to Darnell organisms that consume detritus are thought to digest the microbial community and pass the organic substrate relatively unaffected. However, Haines (1976a) and Haines and Monttague (1979) questions the sweeping validity of the above theory. Haines carried out isotopic studies, which seem to indicate that organic detritus itself is a major dietary component in many fish species. He however acknowledges that organic detritus can serve only as a carrier of microbial community into the stomachs of some fish species and that the microbial community is the real food from a detrital source rather than the substrate.

Silt is recorded in the diet of many fish. Silt and organic detritus can be very difficult to distinguish during gut contents examination. A technique employed in this study to distinguish organic detritus and mineral matter silt is to feel the particles and then dispersed in distilled water. The grains of mineral silt tend to be smaller and also disperse more easily. Under a microscope mineral particle mostly vermiculite and montmorillonite are easily distinguishable from organic matter. Bowen (1983) used dye stains to distinguish between organic detritus and silt. Silt may have been eaten intentionally and may have some nutritional value if some of the particles are organic or if they have attached micro-organisms. Probably, in many cases, silt is ingested involuntarily as the fish forage for burrowing organisms such as chironomid larvae or tubifex worms.

Terrestrial insects

Terrestrial insects appear in the diet of some fish. They are either adult insects which fall or are washed into the estuary from upstream or emergent insects such as chironomids which leave the water and swarm at the water surface where they may be taken by surface feeding fish. In partial digestion terrestrial insects are difficult to distinguish from aquatic invertebrates. Special care needs to be paid to the examination of parts of the head and wings if present.

Water weeds

Water weeds occur as marginal weed beds at some sites notably Teddington, Belvedere and Grays or they may be washed down from upstream of the Thames or its tributaries. Fish browsing at the river margins can consume these organisms although no fish in the Thames estuary are obligate herbivores.

Algae

Algae are present in the river as epiphytic and epilithic encrustations and also in the water column as phytoplankton. Detailed analysis of the algal contents of the diet was not made but most of the algae were diatoms and encrusting forms.

5.4.2 The observed food habits of the 12 fish species

Appendix 5, Tables 1 to 6 the number of fish from the 10 sampled in each category eating particular food items is recorded as a diet matrix. The Appendix also indicates the percentage of food items belonging to the three main categories i.e. Crustacea, fish and other as percentage frequency of occurrence (O*i*). The results have been analysed for the range of individuals consumed by particular species, age class, zonal position and season. Appendix 5 is the primary data from which all ecological indices used to describe the feeding strategies of the 12 selected fish species have been derived.

5.4.3 Perch *(Perca fluviatilis)*

Perch distribution

Perch is normally a freshwater species and occurs, as both juveniles and adults in the low salinity water of Zone 1. Adults are also frequent in the brackish water zone 2. In Zone 1 the young perch were abundant and were observed to form small schools, gathered under boats and under the bridges. In Zone 2, 0+ year group were rare but 1+ individual were frequent.

Perch diet

0+ Zone 1 Summer

In summer 100% of 0+ year old perch ate small crustaceans particularly gammarids but also branchiopods, amphipods and isopods. The fish also ate other food items: 70% had consumed gastropods and 30% worms and chironomids. Detritus was found in 70% of the stomachs. 100% of the fish sampled had consumed fish, mainly roach and mullet but also goby and sticklebacks. In terms of % frequency of occurrence (O*i*) of food items recorded, Crustacea formed the majority 52%, Other 25% (including Oligochaetes) and Fish 23%.

0+ Zone 2 summer

In Zone 2 all the 0+ Perch consumed several different groups of Crustacea particularly copepods, amphipods, branchiopods and cyprid larvae. Other food items foraged frequently included oligochaetes (80%), gastropods (80%) and chironomids (60%). The major difference between the diet of 0+ perch in summer in zones 1 and 2 was that the only fish fry taken in Zone 2 was smelt which had been consumed by 70% of the fish sampled. This was probably due to the breeding of smelt and the scarcity of most of the more typical freshwater species of fish fry in this zone. The scarcity of many fish fry species resulted in their frequency of occurrence in the diet being 23% in Zone 1 and 9% in Zone 2. In contrast the O*i* value of 'Crustacea' was 52% and 59% and 'Other' was 25% and 32% in zones 1 and 2 respectively.

Perch 1+ Zone 1 summer

Examination of the gut contents of the older perch in Zone 1 revealed a wide range of food items including gammarids (100%) and other crustaceans, chironomids (80%), terrestrial insects (60%), oligochaetes (40%) and gastropods (20%). However the most obvious feature of the diet of these older fish was that there was a much larger fish component in the diet with roach and flounder fry taken by all the older fish sampled and dace, bleak, goby sticklebacks, perch and smelt also being consumed. The *Oi* (frequency of occurrence) value of fish items in stomach was 44% compared to 23% for 0+ fish whilst the *Oi* value of 'Crustacea' and 'Other' were down to 35% and 21% respectively.

Perch 1+ Zone 2 summer

In Zone 2 in summer the larger fish also showed a marked increase of fry in their diet compared with 0+ fish. A wide range of fish fry species were taken including typically freshwater species such as roach, bleak and dace and also more estuarine and marine species such as smelt, flounder, mullet and bass. 57% is the *Oi* value of 'Fish' in 1+ perch compared with less than 10% for 0+ fish from this zone in summer. The *Oi* value of 'Crustacea' fell from 59% for 0+ to 39% and 'Other' food items fell to 4% compared with 32% for the 0+ fish

Perch 1+ Zone 1 winter

The diet of the larger Perch in Zone 1 in winter showed a complete absence of fish in their diet. This tied in with the failure to catch any O+ fish in winter. During the winter these fish, therefore, rely on 'Crustaceans' particularly gammarids, (100%), copepods (100%) and branchiopods (100%) and also isopods, amphipods and crangonids. The *Oi* value of 'Crustacea' was 71%, 'Others' at 29% consisted mainly of chironomids. Significant in their absence in the diet were terrestrial insects which would not be expected to be emerging or active at this time of year.

Perch 1+ Zone 2 winter

In Zone 2 in winter the older fish also eat primarily Crustaceans. Overall *Oi* value of 'Crustacea' in the gut contents of perch in winter was 63%. The only 'Other' item present was detritus. Unlike fish of the same age group in Zone 1, the frequency of occurrence of fish in the diet remained high at 30% of food items foraged and included roach, mullet, goby and dace fry.

5.4.4 An overview of Perch diet

0+ Perch predominately consumed 'Crustacea' and 'Other' food items of appropriate size when available. They also consumed small fry such as roach in Zone 1 and smelt in Zone 2 if they were small enough in summer shortly after hatching. Older perch (1+ fish) showed a marked transition to feeding on fish fry with Crustacea and other items becoming secondary. However, if fish fry were unavailable as in winter Zone 1 and to a lesser extent in winter Zone 2, the larger perch fed mainly on Crustacea.

5.4.5 Dace *(Leuciscus leuciscus)*

Dace distribution

Dace is a freshwater species but penetrates well into the Zones 1 and 2 of the estuary. Typically dace are found in schools (both 0+ and 1+ groups) in the upper estuary (Zone 1) Teddington, Hammersmith and Battersea sites, especially in summer. These sites have clean and deep water of very low salinity. The 1+ age groups appear to be more adaptable to variable saline conditions and are more frequently found in zone 2 than the fry.

Dace Diet

Dace 0+ Zone 1 summer

0+ Dace fed almost equally on 'Crustacea' with *Oi* value of 'Crustacea' of (49%) and 'Other' items (51%). Significant records of gammarids and amphipods, detritus, water weeds and algae showed an omnivorous diet but with a relatively narrow range (Table 5.3). Fish were not found in the diet of dace.

Dace 0+ Zone 2 summer

In Zone 2 the 0+ Dace diet was again restricted (Table 5.3) with a similar balance of 'Crustacea' ($Oi = 54\%$) and 'Other' ($Oi = 46\%$) but instead of algae and water weeds the 'Other' component included oligochaetes and chironomids and only one record of terrestrial insects. Detritus was present in all stomachs perhaps due to their foraging for burrowing chironomids and oligochaetes.

Dace 1+ Zone 1 summer

The larger dace had a similar diet to the 0+ fish from the same zone but with a slight preponderance of 'Other' (Oi = 54%) compared with 'Crustacea' (Oi = 46%) due to the greater number of fish taking terrestrial insects, chironomids and oligochaetes.

Dace 1+ Zone 2 summer

Larger dace in Zone 2 showed a virtually identical Oi values of 'Others' (55%) and 'Crustacea' (45%) compared with Zone 1 but, interestingly, the terrestrial insects (30%) were found less frequently as were chironomids (30%) whereas polychaetes (60%) and gastropods (30%) featured in the diet in this zone. This reflected the more estuarine nature of Zone 2.

Dace 1+ Zone 1 winter

In winter the larger dace in Zone 1 foraged mainly for 'Crustacea' (Oi = 59%) whilst 'Others' comprised 41% consisting of only oligochaetes and chironomids. No terrestrial insects occurred in the diet. Detritus was recorded from all stomachs examined, probably linked with the foraging for worms and chironomids.

Dace 1+ Zone 2 winter

In Zone 2 the winter diet of larger dace appeared very restricted. Only five types of food were recorded: branchiopods, gammarids, detritus, oligochaetes and amphipods. The ratio of the Oi values for 'Crustacea' (56%) to 'Other' (44%) was similar to that recorded elsewhere. Dace had a very restricted diet in Zone 2 in the winter season.

5.4.6 Overview of dace diet

The most striking feature of the dace diet is the restricted number of types of food items taken, its diet width (the number of food items consumed) ranging from 7 in 0+ fish in Zone 1 in summer to only 5 for the larger fish in Zone 2 in winter. The differences in the guts contents between the dace examined in Zones 1 and 2 were probably due to differences in availability rather than preferences. In Zone 2 water weeds and terrestrial insects were not abundant food sources. The rarity of riparian vegetation and the presence of concrete walls in Zone 2 reduced the habitats of terrestrial insects.

5.4.7 Roach *(Rutilus rutilus)*

Roach distribution

This is a fresh water species dominating all catches of fresh water fish in the upper estuary, but it is also found in the brackish water, Zone 2. The spawning period is April – June.

Roach diet

Roach 0+ Zone 1 summer

The diet of 0+ roach in the summer in Zone 1 was very similar to that of dace with a diet of gammarids and amphipods being recorded in the large majority of fish and significant records of algae, water weeds and detritus. However, the exception was that the 0+ roach fry consumed chironomids. This gave a slight shift in balance between 'Crustacea' (Oi = 51%) and 'Other' (Oi = 49%). Roach breed earlier than dace and thus being slightly larger can probably consume chironomids earlier in the year.

Roach 0+ Zone 2 summer

The 0+ roach in Zone 2 Summer consumed mainly Crustacea (Oi = 61%) including small Copepods and Branchiopods as well as larger Gammarids and Amphipods. Roach consumed fewer Oligochaetes and Chironomids than dace and much less detritus was ingested. An addition to the roach diet compared with dace of the same zone and size was gastropods. Interestingly larger dace consumed gastropods in Zone 2. The Oi value for other food items was 39. 0+ Roach consumed no fish in Zone 2.

Roach 1+ Zone 1 summer

Larger roach in Zone 1 during summer displayed a marked shift from the 0+ diet of mainly 'Crustacea' to a majority of 'Other' food items particularly chironomids and terrestrial insects which were both consumed by all the fish sampled and an increase in both gastropods (60%) and oligochaetes (40%). An increase in silt and detritus probably reflected foraging for the burrowing fauna. The 'Crustacea' consumed shifts from mainly small copepods and branchiopods to larger gammarids, amphipods and isopods

Roach 1+ Zone 2 summer

In Zone 2 the diet of larger roach was similar to Zone 1 apart from the absence of terrestrial insects and the appearance of Polychaetes (60%) in the diet. Also the Oligochaetes were consumed more frequently (90%) and the Chironomids less (40%). Detritus (100%) and Silt

(80%) were consumed by most of the fish sampled probably as a result of foraging for oligochaetes and polychaetes.

Roach 1+ Zone 1 winter

The diet of larger roach in Zone 1 in winter appeared fairly restricted with 9 food types namely: branchiopods, gammarids, amphipods, copepods, isopods, oligochaetes, chironomids, gastropods and detritus occurring in all the stomachs. Also present in a significant number of fish guts were amphipods (60%) and gastropods (60%). Once again winter samples did not contain terrestrial insects. The ratio of *Oi* values for 'Crustacean' to 'Other' food items was 47:53 compared with 33:67 in summer probably, reflecting the unavailability of terrestrial insects.

Roach 1+ Zone 2 winter

Only six food types were taken by the larger roach in Zone 2 during winter with 'Crustacea' (*Oi* = 67%) predominant over 'Other' (*Oi* = 33%). The only non crustacean items taken were detritus (100%) and oligochaetes (100%) which were consumed by all the fish sampled.

5.4.8 Overview of Roach diet

Like dace, roach were omnivorous feeding on a wide variety of food types and were not piscivorous. 0+ Roach fed on a variety of food items including plants as well as 'Crustacea'. As the fish grew larger there was an increase in foraging for chironomids, terrestrial insects, oligochaetes and gastropods during the summer but some of these food items were apparently less available or non-available in winter e.g. chironomids and terrestrial insects respectively.

5.4.9 Gudgeon *(Gobio gobio)*

Gudgeon distribution

Gudgeon is a very important species in the Thames Estuary. This species contributes a significant population of cohorts that distribute themselves very widely in the estuary. Gudgeon is a bottom living species is particularly abundant in the clean and slower flowing water of Teddington just below the lock although a significant population of 1+ have been encountered in the brackish water boundaries. They are found in areas with gravel substrates. In winter, 1+ gudgeons are mostly caught in areas around Greenwich and Belvedere where the water is deep.

Gudgeon Diet

Gudgeon 0+ Zone 1 summer

0+ gudgeon fed on a variety of 'Crustacea' (*Oi* = 54%) and 'Other' food items (*Oi* = 46%). The crustacean elements of the diet included gammarids (100%) amphipods (90%) and copepods (80%). oligochaetes (100%), detritus (100%) and silt (70%) were the 'Other' food items consumed. The absence of terrestrial insects and the predominance of oligochaetes, detritus and silt reflected the mouth structure and behaviour of this species which has a down-turned sucking mouth for benthic foraging.

Gudgeon 0+ Zone 2 summer

In Zone 2 the 0+ fish diet showed a similar balance of 'Crustacea' to 'Other' food items (*Oi* ratio = 53:47). Perhaps surprisingly small marginal and planktonic crustaceans (branchiopods, cyprid larvae and copepods) were predominant and no gammarids or amphipods were recorded. Chironomids also featured in the diet of many Zone 2 fish which were absent in Zone 1.

Gudgeon 1+ Zone 1 summer

Larger gudgeon in Zone 1 in summer fed primarily on 'Crustacea' (59%) of which the larger forms, amphipods and gammarids occurred in all guts. Branchiopods (80%), Isopods (60%) and Crangonids (20%) were also taken. As well as chironomids (100%) and oligochaetes (50%) the gudgeon also foraged for gastropods (60%) and terrestrial insects (60%). Other items represented 38% of food items. Rather surprisingly, as gudgeon are not generally thought to be piscivorous, one gudgeon had eaten another fish (goby fry).

Gudgeon 1+ Zone 2 summer

In Zone 2 the larger gudgeon ate an even balance of 'Crustacea' and 'Other' Food items (*Oi*s ratio = 50:50). Differences observed between Zone 1 and 2 were the presence of high proportions of crangonids (80%) and polychaetes (80%) whilst terrestrial insects were absent no doubt reflecting the more brackish nature of Zone 2. Like the larger fish in Zone 1, gastropods (60%) were present in the diet which had not been found in 0+ fish.

Gudgeon 1+ Zone 1 winter

The balance of food items in winter for large gudgeon showed a predominance of 'Crustacea' (*Oi* = 54%) compared with 'Others' (*Oi* = 43%) reflecting the absence of terrestrial insects. A confirmation of the fact that larger gudgeon will consume fish fry was obtained as both smelt and goby fry were recorded in the diet.

Gudgeon 1+ Zone 2 winter

'Crustacea' (*Oi* = 62%) formed a greater component of food items than 'Other' (*Oi* = 37%) for these fish reflecting an absence of chironomids and terrestrial insects from the diet compared with the summer samples. Silt (100%) and detritus (100%) seem to indicate that gudgeons were still actively foraging for benthic organisms in winter.

5.4.10 Overview of Gudgeon Diet

The gudgeon diet clearly overlapped with that of dace and roach. The main difference was that 5 fish were recorded in the stomachs of the larger fish examined. Although this represented only a very small fraction of the food items recorded it indicates an ability to adopt a piscivorous diet.

5.4.11 Bream *(Abramis brama)*

Bream distribution

The common bream is a freshwater cyprinid fish typical of lowland reaches of rivers where current flow is low and the substrate is muddy. In this study it was surprisingly captured primarily from Greenwich although it was also present in Teddington, Hammersmith and Battersea in much reduced numbers.

Bream Diet

0+ Bream Zone 1 summer

In Zone 1 the bream fry consumed mainly 'Crustacea' (Oi = 68%) including gammarids (100%), copepods (100%), cyprid larvae (90%) and isopods (60%). Oligochaetes (100%), detritus (80%) and water weeds (30%) make up the 'Other' component of the diet (Oi = 32%).

Bream 0+ Zone 2 summer

The diet of 0+ bream in Zone 2 was essentially similar except that chironomids (70%), gastropods (60%) and polychaetes (10%) also featured in the diet reversing the Oi values balance of 'Others':'Crustacea' to 57:43.

Bream 1+ Zone 1 summer

The diet of larger bream in Zone 1 in summer was 59% 'Crustacea' including a wide variety of types. The 'Other' group (Oi = 41%) includes terrestrial insects (60%), waterweeds (50%), oligochaetes (100%), chironomids (100%) and gastropods (40%).

Bream 1+ Zone 2 summer

In Zone 2 the diet of the larger bream was still predominately 'Crustacea' (Oi = 59%) and included a wide range of types including crangonids. The 'Other' category stood at Oi = 38% with no terrestrial insects fewer water weeds (20%) but significant algae (70%) and a few polychaetes (20%). There was also fish in the diet (Oi = 3%) The diet thus reflected the more brackish nature of the habitat. Smelt fry also appeared in the diet.

Bream 1+ Zone 1 winter

The Zone 1 winter diet of larger bream was very similar to that of the summer diet except for the expected absence of terrestrial insect and reduced (20%) consumption of water weeds. The Oi of 'Crustacea' was 64% and that of 'Other' was 36%.

Bream 1+ Zone 2 winter

The larger bream in Zone 2 in winter had a rather restricted diet of only 8 food types compared with 14 in the summer. The diet was even more predominantly 'Crustacea' (Oi = 84%) with oligochaetes (100%) as the only 'Other' item taken.

5.4.12 Overview of Bream Diet

Bream like the other cyprinids fed almost exclusively on 'Crustacea' and 'Other' items. In the summer its food intake diversified to include water weeds, algae and terrestrial insects but these diminished in the winter. It was interesting to note that the silt and detritus component of the diet was quite high for the 0+ but absent for the larger fish in both zones and both seasons. This differed markedly from the other cyprinids which consumed large quantities of silt and detritus when they were feeding on oligochaetes and chironomids. Presumably this difference must reflect a different feeding technique with the bream taking items cleanly rather than sucking them in with associated debris.

5.4.13 *Eel (Anguilla anguilla)*

Eel distribution

This fish exists throughout the range of the estuary, but is recorded more frequently in Zone 1. The eels captured in the Thames Estuary are immature individuals with dark brown back and yellowish, sometimes golden sides and belly. Naismith and Knight (1988) established the basic biology of the eel in the Thames Estuary. Glass eels at 65mm appear in the estuary in early April although in small numbers

Eel Diet

Eel 0+ Zone 1 summer

In Zone 1 the 0+ eels had a diet comprising a balance of Oi = 32% 'Crustacea', Oi = 53% 'Others' and Oi = 15% 'Fish'. The predominant items were gammarids (100%) and detritus (100%) and silt (100%) followed by oligochaetes (80%) polychaetes (70%), crangonids (60%) and chironomids (40%). Clearly these young eels are feeding mainly on the benthos although they took a variety of fish fry including the fry of roach, flounder and dace. It was interesting that this species had selected polychaetes and crangonids which were not consumed by 0+ dace, roach, perch or gudgeon in this zone.

Eel 0+ Zone 2 summer

In Zone 2 the 0+ eels had a similar diet to those of Zone 1 but with more prevalence of 'Crustacea' (Oi = 50%) compared with 'Other' items (Oi = 41%). 'Fish' comprised a somewhat lower (Oi = 9%) value of the food items taken and consisted of one species only, smelt. Oligochaetes and chironomids were taken by all the young eels and the majority also took gammarids (90%), amphipods (90%), isopods (70%) crangonids (50%), copepods (50%) and polychaetes (50%)

Eel 1+ Zone 1 summer

The diet of the larger eels in Zone 1 in summer was very diverse with 23 different types of food items recorded. The food items taken by eels showed a marked change towards a piscivorous life style. 'Fish' represented nearly half the food items taken (Oi = 46%) and included a wide variety of species namely the fry of perch, smelt, bleak, roach, dace, flounder, mullet, goby, stickleback and sea bass. 'Crustacea' component of the diet had an Oi value of 32% of the food items present with gammarids and amphipods present in all the stomachs examined. 'Other' food items had an Oi value of 21% and included chironomids (100%), terrestrial insects (60%) oligochaetes (60%) and gastropods (30%).

Eel 1+ Zone 2 summer

As in Zone 1 the diversity of food types in the diet was very high. The shift in the diet of older eels to a piscivorous diet was also seen during the summer in Zone 2. The actual Oi of fish in the diet was not quite as high (32%) but the same variety of species was taken. The occurrence of crangonids (100%) and polychaetes (90%) in the diet of fish in this zone keeps the level of 'Crustacea' (Oi = 35%) and 'Other' food items (Oi = 33%) quite high.

Eel 1+ Zone 1 winter

The diversity of food items taken in the winter by the larger eels was considerably lower (niche width = 10). In winter in Zone 1 the larger eels had Oi value of only 25% 'Fish' component and from only four species rather than 10 in the summer. The species consumed included perch, roach, smelt and mullet. The reduction in fish as a % of the whole diet and the lower diversity of fish species taken reflected the much lower levels of fish fry in this zone during winter months. Amongst the food items consumed, gammarids, isopods, detritus, oligochaetes and chironomids were taken by all the fish examined. 'Crustacea' appeared in the diet more frequently (Oi = 43%) followed by 'Other' (32%).

Eel 1+ Zone 2 winter

The reduction of food diversity in the guts in winter was also observed in Zone 2 where only 12 food types were taken. The Oi value of 'Fish' in the diet was 29%. This is similar to the summer figures for this zone (Oi = 31%) but much lower than the figure for Zone 1 in the summer (Oi = 46%). Only 4 different species were taken including mullet fry and roach fry as in Zone 1 but also goby and sticklebacks as opposed to perch and smelt. The Oi values ratio of 'Crustacea' to 'Other' food items balance was 47:24 compared with 43:32 in Zone 1 during the same period reflecting much lower oligochaete records (20%) and no chironomids in the diet.

5.4.14 Overview of Eel Diet

In general one could see that the diversity of food types taken by eels was very large and was about twice as high as the cyprinids. A part of this is the tendency of eels to consume fish fry species when available. Although 0+ eels did consume some fish it was the 1+ eels that became significantly piscivorous. This was particularly marked in Zone 1 during the summer when a wide variety of fish fry were present. The 'Fish' item in the diet of larger eels in zone 2 were lower and probably reflect the availability of suitable size fry. In the winter the 'Fish' component in the diet was less than Oi = 30% in both zones. It should be noted here that the eels taken of 1+ were not generally very big and one might well expect and continuing trend towards piscivory in the large eels not sampled.

5.4.15 Flounder (*Platichthys flesus*)

Flounder distribution

This is a marine fish that breeds in relatively shallow water on the estuary (Wheeler, 1985). Catches in this study and fish data from the Environment Agency indicated that flounder continues to be the most abundant estuarine species in the tideway.

Flounder diet

Flounder 0+ Zone 1 summer

It was not easy to determine the gut contents of small post-larval stages as the fish themselves were so small. The small 0+ fish consumed mostly silt. Of the recognisable organism, gammarids, chironomids and oligochaetes were taken by all the fish examined. Cyprid larvae (60%), polychaetes (70%) and gastropods (30%) and completed the dietary range. The inclusion of polychaetes in the diet from this zone was interesting as these were not taken by the more typical freshwater fish species but were also eaten by eels, smelt and mullet. Bleak fry were taken by one flounder. The Oi values of 'Crustacea', 'Other' and 'Fish' were 32%, 53% and 15% respectively.

Flounder 0+ Zone 2 summer

The flounders in Zone 2 consumed a much wider range of 'Crustacea' (O*i* = 49%) and most of the fish examined had eaten at least three different types. The identified 'Other' organisms showed *Oi* value of 49% comprising mainly oligochaetes and gastropods, 80% consumed chironomids and 60% polychaetes. Two of the flounders examined had consumed smelt fry. The wider food range of 0+ fish in this zone may simply reflect the fact that the fish examined were larger than those caught in Zone 1.

Flounder 1+ Zone 1 summer

The larger flounders in Zone 1 had a diet similar to 0+ from Zone 2, i.e. a wide range of 'Crustacea' together with chironomids (100%), gastropods (100%) and oligochaetes (60%). Polychaetes however were only taken by 10% of the fish examined. Once again two flounders had taken fish (goby fry)._The Oi values for 'Crustacea', 'Other' and 'Fish' were 53%, 43% and 4% respectively.

Flounder 1+ Zone 2 summer

In Zone 2 the flounders consumed a diet containing significantly less 'Crustacea' (O*i* = 41%), 'Other' (Oi = 47% and more 'Fish' (*Oi* = 12%), mostly smelt and goby. As one might expect polychaetes (90%) were consumed by most of the flounders in this zone.

Flounder 1+ Zone 1 winter

In the winter in Zone 1 the diet of the larger flounder was essentially the same as seen in the summer apart from the absence of cyprid larvae and the presence of crangonids (30%) amongst the 'Crustacea' taken.

Flounder 1+ Zone 2 winter

In Zone 2 in winter the larger flounders showed a marked reduction in fish fry (*Oi* = 10%) compared with the same Zone in the summer. They took a lot of detritus (100%) and silt (100%) and the range of food items was down from 25 to 10 seasonally.

5.4.16 Overview of Flounder diet

The flounders primarily fed on benthic invertebrates although a lot of silt and detritus was consumed by the very small 0+ fish in Zone 1 and by the larger fish in winter in Zone 2. Flounders of all ages appear to take fish opportunistically but only for the larger fish in Zone 2 in winter do fish form a significant component of the diet. In terms of diversity of food types taken the smallest flounders in Zone 1 had a very restricted diet. This is most probably due to their very small size at this point. The 1+ flounder on the other hand had a wider range (average niche width of 12 per zone and season) than the cyprinids (9) but smaller range than eels and perch where the ability to consume a wide variety of fish fry species raised diversity levels to 20+ food types in summer and 12+ food types in winter. Perhaps significantly the greatest difference between cyprinids and flounder in diversity of food types taken was in winter when the cyprinids had a restricted range of food items taken, particularly in Zone 2 (8 food types).

5.4.17 Smelt *(Osmerus eperlanus)*

Smelt distribution

This is an inshore marine migratory species, which spawns in fresh water or where the salinity is very low. In the Thames Estuary smelt are abundant in the brackish water zones although they penetrate the fresh water zone as far upstream as Hammersmith

Smelt diet

0+ Smelt Zone 1 summer

In Zone 1 the smelt fry fed predominately on 'Crustacea' (Oi = 66%) and 'Other' items (Oi = 9%) were polychaetes making a predominantly invertebrate diet. All the fish examined consumed a wide variety of 'Crustacea' including amphipods, crangonids gammarids, copepods and isopods. Clearly the fish feed both on the benthos and on mid water species. No terrestrial insects were consumed or oligochaetes or chironomids. The fish were obviously highly selective. The Oi value of 'Fish' part of the diet was 25% and included a wide range of species with their own predominant (60%) and mullet (40%)

0+ Smelt Zone 2 summer

In common with several other species the fry of smelt did not find fish of suitable size in Zone 2 in summer and the diet was entirely restricted to 'Crustacea' (Oi = 100%).

Smelt 1+ Zone 1 summer

The larger smelt in Zone 1 in summer consumed 'Fish' predominantly (Oi = 55%) and additionally a variety of 'Crustacea' (Oi = 45%). Eight different fish species were taken including 100% of fish consuming sea bass, sticklebacks, goby, dace, flounder and roach.

Smelt 1+ Zone 2 summer

In Zone 2 the larger smelt consume a wide variety of food with a balance of 'Fish' (Oi = 45%): 'Crustacea' (Oi = 50%) and 'Others' (Oi = 5%). Again eight different fish species are taken including flounder (90%) sea bass (90%), goby (80%), smelt (80%) and mullet (70%) as the predominant species.

Smelt 1+ Zone 1 winter

In Zone 1 in winter the larger smelt fed entirely on 'Crustacea' with all fish feeding on branchiopods crangonids, gammarids amphipods and copepods and 50% taking isopods. The fish thus had an extremely restricted diet of only 6 food types.

Smelt 1+ Zone 2 winter

In Zone 2 in winter the larger smelt consumed 'Crustacea' (67%) and 'Fish' (33%) and surprisingly all the fish contained the same nine food items namely Branchiopods, crangonids, gammarids, amphipods, copepods, isopods as well as roach, mullet and goby fry.

5.4.18 Overview of Smelt diet

Smelt fed almost exclusively on 'Crustacea' and Fish with 0+ fish being mainly 'Crustacea' feeders and the larger fish taking a wide variety of fish fry species when they where available but not for example in Zone 1 in winter when the fish fry had largely disappeared.

5.4.19 Sea bass *(Dicentrarchus labrax)*

Sea bass distribution

This is a very frequent species in the brackish and marine zones of the estuary (Zones 2 and 3 respectively). The larval, post larvae, 0+ and 1+ Sea bass use the estuary as a feeding ground, (Wheeler, 1979). In this study 0+ year class bass were collected at Battersea, Greenwich and Belvedere between the months of May (late May), June, July and August. In the months of August, September and October a mixture of different lengths of the fish were caught. In winter 1+ year classes gathered in Grays site. This site has warm water from engine cooling systems from the granary factory in Grays. Wheeler (1979) describes this fish as a warm water dwelling species.

Sea bass diet

0+ Sea bass Zone 1 summer

The sea bass caught in Zone 1 during the summer fed on a mixture of 'Crustacea' (Oi = 68%) and fish fry (Oi = 32%). The 'Crustacea' taken included mainly gammarids (100%) and amphipods (100%) and crangonids (90%). A wide variety of fish species were taken but there seemed to be a preference for mullet (60%) and smelt (40%) which were typically more brackish water species.

0+ Sea bass Zone 2 summer

In Zone 2 the diet of sea bass was similar but with smelt being the only fish species taken, there appeared to be greater dependence on 'Crustacea' (Oi = 78%). Polychaetes worms were also taken in this zone. The O*i* values for fish 'Other' and 'Fish' were 9% and 14% respectively.

Sea bass 1+ Zone 1 summer

In Zone 1 in summer the sea bass took advantage of the plentiful supply of fish fry from a variety of species. 'Crustacea' (*Oi* = 49%) and Fish (*Oi* = 48%) were fairly evenly balanced. The range of fish taken included many cyprinids; roach (100%) and dace (60%) as well as flounders (90%) and mullet (50%). The sea bass also consumed perch fry and fry of its own species, which was an indication of its voraciousness as these were relatively large and spiny fry.

Sea bass 1+ Zone 2 summer

For the larger sea bass in Zone 2 in summer the 'Fish' component comprise *Oi* value 52% of with smelt (90%) goby (90%) mullet (80%) and young bass fry (80%) indicating a strong preference for marine rather than freshwater cyprinid species. A few 'Other' items (*Oi* = 4%) including oligochaetes, chironomids and polychaetes were taken but otherwise the diet was mainly 'Crustacea' (*Oi* = 44%) with amphipods, gammarids and crangonids predominant.

Sea bass 1+ Zone 1 winter

In winter in Zone 1 the sea bass relied almost exclusively on 'Crustacea' (*Oi* = 93%) with a few 'Other' items (*Oi* = 7%) and no fish taken. This was an extremely marked change in diet and perhaps indicated the marginal suitability of Zone 1 for sea bass in winter.

Sea bass 1+ Zone 2 winter

In zone 2 the older sea bass continued to feed on 'Fish' to a certain extent (*Oi* for 'Fish' = 32%) but the *Oi* of 'Crustacea' as a component of the diet increased to 67%. The fish fry taken includes mullet (100%) flounder (100%) and goby (70%).

5.4.19 Overview of Sea bass diet

It was apparent that the Sea bass had a preference for fish fry in their diet if they were available and thus 0+ fish in summer in Zone 1 took advantage of the newly hatched cyprinids whereas in Zone 2 they were dependent on Crustacea. For the larger sea bass, fish fry were present in the diet in both zones in summer but were much reduced in winter. Sea bass were known to be essentially summer migrants to the estuary and it appeared that the supply of fish fry must be linked to this. In summer the food types taken by larger sea bass were higher (19) than in winter (9) showing clearly a much more varied diet in the summer months.

5.4.20 Thin-lipped Grey Mullet *(Liza ramada)*

Mullet habitat

The mullet is a marine species which spawns at sea. Fry enter estuaries which are used as a nursery ground. Thin-lipped Grey Mullet live in the sea, but also invade rivers, where they may swim quite a long way upstream and are the commonest grey mullet found in freshwater. During the year they undertake spawning and food migrations and may be found in more northerly waters in the summer. Spawning takes place in the sea in more northerly waters, usually at night (Pivnicka and Carney, 1998). During the year they undertake spawning and feeding migrations. In the Thames Estuary, mullets are the first visitors to enter the estuary when tide water begins to rush in.

Mullet diet

Mullet O+ Zone 1 summer

0+ mullet had the most restricted diet of all the fish in Zone 1. The O*i* values of diet items comprised 11% 'Crustacea' and 89% 'Other'. The main food items identified were detritus (100%) and oligochaetes (100%). Some gastropods and cyprid larvae were also consumed. The mullet is known in other habitats to feed on benthos and vegetation. It is likely the detritus was unidentifiable vegetable matter.

Mullet 0+ Zone 2 summer

In Zone 2 the 0+ mullet also had a very restricted diet of only 4 food types including mainly Silt (100%) and detritus (100%) but also some branchiopods(40%) and copepods (60%).

Mullet 1+ Zone 1 summer

The larger mullet in Zone 1 had a much more diverse diet (14 food types) including 'Crustacea' (O*i* = 39%) and 'Other' (O*i* = 61%). The 'Crustacea' included predominantly gammarids (80%) and amphipods (100%) whilst 'Other' included mainly gastropods (100%), oligochaetes (80%) and chironomids (70%). Algae (50%) were also consumed. The fish were now clearly feeding mainly on benthic invertebrates and much less detritus was taken although some silt was ingested.

Mullet 1 and 1+ Zone 2 summer

In summer in Zone 2 the larger mullet consumed mostly 'Other' food items (Oi = 68%) which included algae, detritus, silt and oligochaetes (all taken by 100%) as well as polychaetes, gastropods and chironomids. 'Crustacea' (Oi = 26%) and 'Fish' (Oi = 6%) formed smaller components of the diet.

Mullet 1+ Zone 1 winter

The larger mullet diet in winter in zone 1 was had similar O*i* values as that of summer with 36% 'Crustacea' and 64% 'Other'. The same 12 food types were taken in about the same proportions.

Mullet 1+ Zone 2 winter

The larger mullet in Zone 2 in winter again consumed mainly 'Other' food items (Oi = 83%) 'Crustacea' were taken less commonly (Oi = 17%). The main difference between summer and winter in this zone was the absence of algae in the diet which could be expected seasonally and a reduced diversity of benthic invertebrates. In fact only 6 different food types were taken including detritus and silt.

5.4.21 Overview of mullet diet

For the 0+ mullet the estuary seems to offer a very restricted diet, only 5 different food types being taken including silt and detritus. The range of food items increased to 11 for the larger mullet in summer but in Zone 2 again the diet was restricted to 6 types including silt and detritus. Algae formed a significant part of the diet of older fish in Zone 1 in summer.

5.4.22 Three-spined stickleback *(Gasterosteus aculeatus)*

Stickleback habitat

Although generally regarded as a freshwater species, the stickleback was found throughout the estuary and can be regarded as a permanent resident as it neither migrates to sea or to the freshwater river as an obligate part of its life cycle. Sticklebacks are nest building and therefore require marginal vegetation and inhabit sheltered marginal waters.

Stickleback diet

Stickleback 0+ Zone 1 Summer

The fry of stickleback in this zone were very small and apart from detritus the only recognisable food items were cyprid larvae, gastropods and roach fry, thus including all categories of food at an early age.

Stickleback 0+ Zone 2 summer

The stickleback fry in this zone were somewhat larger suggesting that the fish bred in Zone 1. More items were recognised in the diet including 'Crustacea' (Oi = 36%) - Amphipods and Gammarids as well as Cyprid larvae, 'Other' items (Oi = 44%) included oligochaetes, chironomids and gastropods, whilst 'Fish' (Oi = 20%) were represented by smelt fry.

Stickleback 1+ and >1+ Zone 1 summer

The older sticklebacks in Zone 1 had a very diverse diet (15 food types) comprising: Crustacea (45%) including amphipods (100%), gammarids (80%) and copepods (80%) as well as small numbers of cyprid larvae, branchiopods and isopods; 'Other' food items (37%) included Silt, oligochaetes, chironomids and gastropods. The silt was probably consumed whilst foraging for oligochaetes by these versatile predators; 'Fish' (Oi = 17%) were represented in the diet by a variety of species including bleak, flounder, dace, goby and other sticklebacks.

Stickleback 1+ Zone 2 summer

In Zone 2 the diet in summer of the larger sticklebacks was similarly diverse with 19 food types including Oi = 37% 'Crustacea', Oi = 30% 'Other' items and Oi = 33% Fish. The more brackish nature of this Zone was reflected in the presence of crangonids (60%), polychaetes and sea bass (60%) in the diet.

Stickleback 1+ Zone 1 winter

The diversity of food items taken in winter held up quite well for the larger sticklebacks with 13 food types. 'Crustacea' (Oi = 41%) and 'Other' food items (Oi = 40%) were similarly represented. Fish (Oi = 19%) remained high including 5 different species of fish fry. The ability to catch fish fry in this zone in winter was not common amongst other piscivorous species.

Stickleback 1+ Zone 2 winter

In winter in Zone 2 the diet diversity of larger sticklebacks fell sharply (7) and they foraged on only 'Crustacea' (*Oi* = 63%) and 'Others' (*Oi* = 37%). No fish fry were taken which was probably indicative of their small numbers in this Zone during winter.

5.4.23 Common Goby *(Pomatoschistus microps)*

Goby Habitat

This is a true estuarine resident species found in shallow water all the year round. Common goby has been caught throughout the entire length of the estuary although it occurs in large numbers in the brackish water middle zone, especially on muddy and sandy shores. The Common goby is not a commercial species but it has been observed in this study to be an important prey species for predatory fishes like sea bass, smelt and perch.

5.4.24 Overview of common goby diet

The goby is a small fish rarely exceeding 30 cm. On examination of its diet in relation to age, season and zone no marked patterns emerge and so only an overview is presented. This small fish eats predominantly 'Crustacea'. The *Oi* of 'Crustacea' in the diet ranges from 53% for larger fish in Zone 1 in winter to 67% for larger fish in Zone 1 in summer. The differences for 0+ fish appeared to be linked to the amount of detritus and silt taken which is high in Zone 1 and may reflect a real choice, or chance ingestion with chironomids and oligochaetes. In the larger fish also polychaetes plus detritus and silt increase the % of 'Other' items in the diet during the summer in Zone 2. This fish appeared to be an obligate benthic feeder.

5.4.25 Overall comparison of the diet of the 12 species of fish

All the fish species examined consumed a varied diet but for some, mainly the fish predators (perch, eel, sea bass and smelt) the diversity of food types taken was much larger than others such as mullet and the cyprinids. No fish specialises in only one of the three categories but many showed a shift towards piscivory as they grew larger. Most of the 1+ fish caught in the small seine net were less than 20 cm in length and it is probable that if larger perch, eels, sea bass and smelt had been caught the trend to piscivory would have been even greater. Different foraging methods could be assumed in some cases e.g. bream fed on oligochaetes without consuming any silt or detritus whereas in all other species silt was associated with the ingestion of oligochaetes and to a lesser extent chironomids. The seasonal trends were marked by the absence of algae and water weeds and terrestrial insects in the winter diets of all fish. Often the winter diets were more restricted and small fish fry seemed less available as a food source in both Zone 1 and Zone 2 during this time of year. In Zone 2 there appeared to be a much greater dependence on 'Crustacea' in the winter months by many species.

5.5 Ecological indices

Ecological indices are numerical values describing the extent or degree at which an ecological phenomenon is expressed.

Diet width

Table 5.3 shows the diet widths of the 0+ and 1+ year classes of 12 fish species selected.

Table 5.3 Diet widths (range of food items consumed by each of the 12 fish species studied)

season	zone	yr class	perch	dace	roach	c'goby	gudeon	eel	bream	flounder	3-s'sback	smelt	s' bass	mullet
summer	1	0+	16	8	8	8	8	13	10	8	4	12	12	4
summer	2	0+	11	8	10	10	7	10	8	14	7	6	8	4
summer	1	1+	22	11	13	11	15	23	11	13	15	15	19	14
summer	2	1+	21	13	14	14	13	24	14	15	19	18	20	11
winter	1	1+	12	8	9	9	13	15	9	13	14	6	8	11
winter	2	1+	11	5	6	8	10	12	7	10	7	9	10	6

The highest diet widths (δ) were recorded in Zone 2 during the summer for 1+ fish especially for eel (δ = 24); followed by perch (δ = 22), sea bass (δ = 20), three-spined stickleback (δ = 19) and smelt (δ = 18). Generally 0+ fish had the lowest diet widths. Winter 1+ fish also displayed smaller diet widths compared to their summer counterparts.

Diet Overlap

Tables 5.4 - 5.9 indicate the computed Diet Overlap (Schoener's index α) for the 12 fish species consisting values for 0+ and 1+ fish examined in Zones 1 and 2 in the winter and summer of 2001. Very high intra-specific and interspecific similarities in the diets of seasonal (winter/summer) and zonal samples were recorded. Inter-specific dietary comparisons indicated that, generally, the diets of all the species, irrespective of age group and zone caught were highly similar except for small variations in win

Table 5.4 Diet overlap (Schoener's index α) amongst fish species (0+ age group) in Zone 1 of the Thames Estuary in the summer of 2001

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.96											
RO	0.96	1.00										
CGB	0.96	0.99	0.99									
GU	0.96	0.99	0.99	0.99								
EEL	0.99	0.97	0.97	0.98	0.97							
BR	0.98	0.98	0.98	0.99	0.99	0.98						
FL	0.97	0.99	0.99	1.00	1.00	0.98	0.99					
3SB	0.89	0.93	0.93	0.92	0.93	0.90	0.91	0.92				
SM	0.99	0.97	0.97	0.99	0.98	0.99	0.99	0.98	0.90			
SBA	0.97	0.98	0.98	1.00	0.99	0.98	1.00	0.99	0.91	0.99		
MU	0.88	0.93	0.93	0.91	0.92	0.89	0.91	0.92	1.00	0.90	0.91	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Table 5.5 Diet overlap (Schoener's index α) amongst species (0+ age group)in Zone 2 of the Thames Estuary in the summer of 2001

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.98											
RO	0.98	0.99										
CGB	0.99	0.99	1.00									
GU	0.97	0.99	0.99	0.99								
EEL	0.99	0.98	0.99	0.99	0.98							
BR	0.98	1.00	0.99	0.99	0.99	0.98						
FL	0.99	0.97	0.98	0.98	0.96	0.99	0.97					
3SB	0.97	0.99	0.99	0.98	1.00	0.98	0.99	0.96				
SM	0.95	0.97	0.97	0.97	0.98	0.96	0.97	0.94	0.98			
SBA	0.98	1.00	0.99	0.99	1.00	0.98	1.00	0.97	0.99	0.97		
MU	0.91	0.93	0.93	0.92	0.94	0.92	0.93	0.90	0.94	0.96	0.93	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Table 5.6 Diet overlap (Schoener's index α) amongst fish species(1+ age group) in Zone 1 of the Thames Estuary in the summer of 2002

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.97											
RO	0.98	0.99										
CGB	0.97	1.00	0.99									
GU	0.99	0.99	1.00	0.98								
EEL	1.00	0.97	0.98	0.97	0.98							
BR	0.98	0.99	1.00	0.99	0.99	0.98						
FL	0.98	0.99	1.00	0.99	1.00	0.98	1.00					
3SB	0.99	0.96	1.00	0.98	1.00	0.98	0.99	0.99				
SM	0.99	0.98	0.99	0.98	0.99	0.99	0.99	0.99	0.99			
SBA	1.00	0.97	0.98	0.97	0.99	0.99	0.98	0.98	0.99	1.00		
MU	0.98	1.00	0.99	0.95	0.99	0.97	1.00	0.99	0.99	0.98	0.98	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Table 5.7 Diet overlap (Schoener's index α) amongst fish species (1+ age group)in Zone 2 of the Thames Estuary in the summer of 2001

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.98											
RO	0.99	0.99										
CGB	0.99	1.00	1.00									
GU	0.99	0.99	1.00	1.00								
EEL	1.00	0.98	0.98	0.98	0.99							
BR	0.99	1.00	1.00	1.00	1.00	0.98						
FL	0.99	0.99	0.99	0.99	1.00	0.99	0.99					
3SB	1.00	0.98	0.99	0.99	0.99	0.99	0.99	0.99				
SM	0.99	0.99	1.00	1.00	1.00	0.99	1.00	1.00	0.99			
SBA	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	1.00		
MU	0.98	1.00	0.99	1.00	0.99	0.98	1.00	0.99	0.98	0.99	0.99	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Table 5.8 Diet overlap (Schoener's index α) amongst fish species (1+ age group) in Zone 1 of the Thames Estuary in the winter of 2001

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.98											
RO	0.99	0.99										
CGB	0.99	0.99	1.00									
GU	0.99	0.98	0.99	0.99								
EEL	0.98	0.97	0.98	0.97	0.99							
BR	0.99	0.99	1.00	1.00	0.99	0.98						
FL	0.99	0.97	0.98	0.98	1.00	0.99	0.98					
3SB	0.99	0.97	0.98	0.98	0.99	0.99	0.98	1.00				
SM	0.97	0.99	0.98	0.98	0.96	0.95	0.98	0.96	0.96			
SBA	0.98	1.00	0.99	0.99	0.98	0.96	0.99	0.97	0.97	0.99		
MU	0.99	0.98	0.99	0.99	1.00	0.99	0.99	1.00	1.00	0.96	0.97	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Table 5.9 Diet overlap (Schoener's index α) amongst fish species (1+ age group) in Zone 2 of the Thames Estuary in the winter of 2001

	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
PER												
DA	0.95											
RO	0.97	0.95										
CGB	0.96	0.99	1.00									
GU	1.00	0.95	0.97	0.97								
EEL	1.00	0.95	0.97	0.96	1.00							
BR	0.97	0.98	1.00	0.99	0.98	0.97						
FL	0.97	0.96	0.98	0.98	0.99	0.99	0.99					
3SB	1.00	0.98	1.00	1.00	0.97	0.97	1.00	0.98				
SM	1.00	0.95	0.97	0.97	1.00	1.00	0.98	0.99	0.97			
SBA	1.00	0.95	0.97	0.97	1.00	1.00	0.98	0.99	0.97	1.00		
MU	0.93	0.98	0.96	0.97	0.93	0.93	0.96	0.94	0.96	0.93	0.93	

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

In the 0+ year group fish of Zone 1 the Schoener's index α, ranged from 0.89 between eel and mullet to 1.00 between roach and dace, common goby and flounder, gudgeon and flounder, common goby and sea bass, bream and sea bass and three-spined stickleback. The general observation was that all species in their 0+ summer preyed heavily on crustacean and oligochaete species. In Zone 2 the 0+ fish Schoener's indices show very similar trends with those of Zone 1 in being high. In this zone the Schoener's index of species diet overlap ranged from 0.90 between flounder and mullet to 1.00 between roach and common goby, dace and bream, gudgeon and three-spined stickleback, dace and sea bass, gudgeon and sea bass and bream and sea bass.

In both zones there was almost complete overlap of diets between all the 12 species. This was also due to the wide spread distribution of planktonic crustaceans as well as oligochaete worms which were preyed upon by all species. All the species modified their diets in winter, reducing the total number of items consumed. However, amongst the 12 species, specialisation in feeding behaviour was not observed.

5.5.1 Diet selectivity Values (Tables 5.10 to 5.15)

Selectivity of fish consumption for the different food items during ontogeny in winter and summer and in the two ecological Zones was assessed using Lawlor index (see page - 195 -). The results are presented in Tables 5.10 to 5.15. The data indicate that crustaceans appear the most in the diet of the fishes all the year round regardless of ontogeny, season or location.

Table 5.10 Selectivity indices (Lawlor index β) of 0+ fish for their food items in Zone 1 of the Thames Estuary in the summer of 2001

	Diet selectivity index (Lawlor index - β)											
Food items/SP	**PER**	**DA**	**RO**	**CGB**	**GU**	**EEL**	**BR**	**FL**	**3SB**	**SM**	**SBA**	**MU**
Branchiopods	0.50	0.06	0.00	0.31	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Crangonids	0.15	0.00	0.00	0.00	0.00	0.15	0.21	0.00	0.00	0.26	0.23	0.00
Gammarids	0.11	0.11	0.09	0.08	0.11	0.11	0.11	0.11	0.00	0.08	0.11	0.00
Amphipods	0.16	0.11	0.11	0.16	0.14	0.00	0.02	0.00	0.00	0.16	0.16	0.00
Copepods	0.07	0.00	0.00	0.00	0.30	0.00	0.37	0.00	0.00	0.26	0.00	0.00
Isopods	0.24	0.00	0.00	0.06	0.03	0.12	0.24	0.00	0.00	0.18	0.12	0.00
Cyprid larvae	0.05	0.05	0.09	0.19	0.05	0.09	0.14	0.14	0.05	0.02	0.07	0.07
Terestrial insects	0.00	0.67	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.08	0.08	0.07	0.10	0.12	0.12	0.10	0.12	0.10	0.00	0.00	0.12
Water weeds	0.00	0.50	0.20	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00
Algae	0.18	0.64	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silt	0.00	0.00	0.00	0.35	0.27	0.38	0.00	0.00	0.00	0.00	0.00	0.00
Oligochaetes	0.05	0.00	0.00	0.17	0.15	0.13	0.17	0.17	0.00	0.00	0.00	0.17
Chironomids	0.12	0.00	0.32	0.00	0.00	0.16	0.00	0.40	0.00	0.00	0.00	0.00
Polychaetes	0.00	0.00	0.00	0.00	0.00	0.29	0.00	0.29	0.00	0.25	0.00	0.17
Gastropods	0.47	0.00	0.00	0.00	0.00	0.07	0.00	0.20	0.27	0.00	0.00	0.00
Perch/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Smelt fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.40	0.00
Bleak/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.33	0.33	0.00
Roach/fry	0.43	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.22	0.04	0.04	0.00
Mullet/fry	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.40	0.00
Flounder/fry	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.33	0.00
Dace/fry	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Goby/fry	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stickleback/fry	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Bass/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = Three-spined stickleback; SM = Smelt; SBA = Sea bass; and MU = Mullet

Perch displayed a moderate selectivity index for branchiopods (β = 0.5); gastropods (β = 0.47); roach fry (β = 0.43); goby fry (β = 1.00); stickleback fry (β = 0.67). Dace displayed relatively high selectivity indices for terrestrial insects (β = 0.67); water weeds (β = 0.5); Algae (β = 0.64). The 0+ fish data also interestingly showed that sea bass and smelt are piscivorous and cannibalistic from an early age. 0+ smelt selected smaller (later) individual of its own species for food with β value for smelt fry of 0.60 and bass fry with (β = 1.00). 0+ sea bass selected perch fry and significantly smelt fry with β values of 1.00 and 0.40 respectively.

Table 5.11 Selectivity indexes (Lawlor index β) of 0+ fish for their food items in Zone 2 of the Thames Estuary in the summer of 2001

	Diet selectivity index (Lawlow index β)											
Food items/SP	**PER**	**DA**	**RO**	**CGB**	**GU**	**EEL**	**BR**	**FL**	**3SB**	**SM**	**SBA**	**MU**
Branchiopods	0.15	0.13	0.11	0.11	0.18	0.00	0.00	0.04	0.00	0.11	0.11	0.07
Crangonids	0.00	0.00	0.00	0.00	0.00	0.38	0.00	0.62	0.00	0.00	0.00	0.00
Gammarids	0.10	0.00	0.09	0.04	0.00	0.13	0.13	0.15	0.07	0.12	0.15	0.00
Amphipods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copepods	0.12	0.12	0.12	0.12	0.11	0.06	0.00	0.02	0.00	0.11	0.12	0.07
Isopods	0.10	0.00	0.04	0.04	0.06	0.15	0.13	0.17	0.00	0.15	0.17	0.00
Cyprid larvae	0.13	0.10	0.11	0.16	0.13	0.00	0.15	0.13	0.06	0.02	0.02	0.00
Terestrial insects	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.06	0.20	0.00	0.06	0.18	0.00	0.18	0.14	0.00	0.00	0.00	0.20
Water weeds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50
Oligochaetes	0.10	0.11	0.09	0.10	0.13	0.13	0.11	0.11	0.11	0.00	0.00	0.00
Chironomids	0.10	0.12	0.05	0.12	0.13	0.17	0.12	0.13	0.07	0.00	0.00	0.00
Polychaetes	0.00	0.00	0.00	0.00	0.00	0.29	0.06	0.35	0.00	0.00	0.29	0.00
Gastropods	0.23	0.00	0.06	0.06	0.00	0.11	0.17	0.26	0.11	0.00	0.00	0.00
Perch/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smelt fry	0.23	0.00	0.00	0.00	0.00	0.19	0.00	0.06	0.26	0.00	0.26	0.00
Bleak/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roach/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mullet/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Flounder/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dace/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goby/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stickleback/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bass/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream;
FL = flounder; 3SB = Three-spined stickleback; SM = Smelt;
SBA = Sea bass; and MU = Mullet

. Perch does not display considerable selectivity in Zone 2. The highest β values were 0.23 for both gastropods and smelt. Roach and dace continue to select terrestrial insects with β values of 0.50 and 0.50 respectively. Mullet had silt as a very frequent item in its gut contents with α β = 0.5

Table 5.12 Selectivity indexes (Lawlor index β) of 1+ fish for their food items in Zone 1 of the Thames Estuary in the summer of 2001

	Diet selectivity index (Lawlor index - β)											
Food items/SP	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	0.07	0.00	0.05	0.13	0.13	0.10	0.10	0.07	0.05	0.17	0.10	0.03
Crangonids	0.14	0.04	0.00	0.00	0.07	0.25	0.00	0.00	0.00	0.14	0.25	0.04
Gammarids	0.09	0.07	0.07	0.09	0.09	0.09	0.09	0.06	0.07	0.09	0.09	0.07
Amphipods	0.07	0.07	0.06	0.06	0.10	0.06	0.10	0.10	0.10	0.10	0.10	0.10
Copepods	0.04	0.09	0.00	0.03	0.12	0.12	0.12	0.14	0.12	0.12	0.12	0.00
Isopods	0.06	0.00	0.06	0.10	0.10	0.06	0.13	0.10	0.10	0.10	0.16	0.05
Cyprid larvae	0.08	0.06	0.04	0.14	0.11	0.08	0.11	0.08	0.06	0.11	0.11	0.01
Terestrial insects	0.13	0.22	0.22	0.02	0.13	0.13	0.13	0.00	0.00	0.00	0.00	0.02
Detritus	0.05	0.09	0.18	0.05	0.27	0.18	0.00	0.09	0.00	0.00	0.00	0.09
Water weeds	0.00	0.31	0.31	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00
Algae	0.00	0.21	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36
Silt	0.04	0.00	0.08	0.00	0.04	0.08	0.00	0.28	0.40	0.00	0.00	0.08
Oligochaetes	0.06	0.09	0.06	0.10	0.07	0.09	0.15	0.09	0.15	0.00	0.04	0.10
Chironomids	0.09	0.06	0.12	0.09	0.12	0.12	0.12	0.12	0.07	0.00	0.01	0.09
Polychaetes	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.67
Gastropods	0.04	0.00	0.12	0.08	0.12	0.06	0.08	0.20	0.12	0.00	0.00	0.20
Perch/fry	0.26	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.17	0.30	0.00
Smelt/fry	0.06	0.00	0.00	0.00	0.06	0.50	0.00	0.00	0.00	0.00	0.38	0.00
Bleak/fry	0.30	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.17	0.17	0.09	0.00
Roach/fry	0.25	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.25	0.00
Mullet/fry	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.86	0.00
Flounder/fry	0.23	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.11	0.23	0.20	0.00
Dace/fry	0.17	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.09	0.29	0.17	0.00
Goby/fry	0.12	0.00	0.00	0.00	0.04	0.16	0.00	0.08	0.08	0.40	0.12	0.00
Stickleback/fry	0.19	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.05	0.48	0.19	0.00
Bass/fry	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.42	0.17	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream;
FL = flounder; 3SB = Three-spined stickleback; SM = Smelt;
SBA = Sea bass; and MU = Mullet

Lawlor values in Zone 1 for the 1+ summer fish ranged from 0.00-0.86. The majority of the notable β values for the 1+ fish were exhibited by perch, smelt, eel and sea bass selecting fish fry. In addition larger crustaceans become more important in the diet of these predatory species than the micro-crustaceans which indicated ontogenetic shifts in the food items consumed. Dace, roach, bream and gudgeon now clearly showed the food items the mature individuals had settled into such as insects, detritus, water weeds, oligochaetes, and chironomids.

Table 5.13 Selectivity indexes (Lawlor index β) of 1+ fish for their food items in Zone 2 of the Thames Estuary in the summer of 2001

	Diet selectivity Index (Lawlor index β)											
Food items/SP	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	0.09	0.13	0.00	0.06	0.17	0.04	0.17	0.06	0.06	0.17	0.04	0.00
Crangonids	0.10	0.01	0.06	0.03	0.12	0.15	0.04	0.12	0.09	0.15	0.13	0.00
Gammarids	0.08	0.04	0.04	0.13	0.08	0.08	0.11	0.10	0.11	0.13	0.11	0.00
Amphipods	0.07	0.09	0.09	0.09	0.06	0.09	0.07	0.08	0.08	0.09	0.09	0.08
Copepods	0.12	0.11	0.11	0.11	0.07	0.09	0.12	0.03	0.07	0.13	0.07	0.00
Isopods	0.09	0.00	0.11	0.12	0.10	0.12	0.05	0.10	0.10	0.02	0.10	0.10
Cyprid larvae	0.01	0.08	0.06	0.14	0.14	0.14	0.14	0.11	0.06	0.01	0.01	0.08
Terestrial insects	0.00	0.50	0.00	0.33	0.00	0.17	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.03	0.13	0.14	0.11	0.14	0.14	0.00	0.13	0.03	0.00	0.00	0.14
Water weeds	0.00	0.00	0.67	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
Algae	0.00	0.00	0.11	0.00	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.53
Silt	0.02	0.12	0.12	0.12	0.12	0.12	0.00	0.15	0.08	0.00	0.00	0.15
Oligochaetes	0.01	0.10	0.10	0.11	0.11	0.11	0.09	0.11	0.11	0.02	0.01	0.11
Chironomids	0.00	0.05	0.07	0.12	0.14	0.14	0.10	0.12	0.12	0.03	0.02	0.10
Polychaetes	0.02	0.10	0.10	0.10	0.13	0.15	0.03	0.15	0.05	0.02	0.03	0.13
Gastropods	0.00	0.05	0.14	0.02	0.11	0.11	0.14	0.16	0.14	0.00	0.00	0.13
Perch/fry	0.67	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.22	0.00
Smelt/fry	0.11	0.00	0.00	0.00	0.00	0.11	0.06	0.15	0.13	0.15	0.17	0.11
Bleak/fry	0.73	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.09	0.00
Roach/fry	0.20	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.40	0.05	0.10	0.00
Mullet/fry	0.24	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.28	0.32	0.00
Flounder/fry	0.19	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.22	0.28	0.13	0.00
Dace/fry	0.47	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.13	0.13	0.00
Goby/fry	0.13	0.00	0.00	0.00	0.00	0.19	0.00	0.13	0.19	0.17	0.19	0.00
Stickleback/fry	0.33	0.00	0.00	0.00	0.00	0.19	0.00	0.00	0.10	0.10	0.29	0.00
Bass/fry	0.16	0.00	0.00	0.00	0.00	0.22	0.00	0.00	0.16	0.24	0.22	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream;
FL = flounder; 3SB = Three-spined stickleback; SM = Smelt;
SBA = Sea bass; and MU = Mullet

In Zone 2 perch, eel, smelt and sea bass continued to exhibit active selection for fish and crustaceans of all sizes but the importance of 'Other' food items was apparent. The selectivity indices were mostly below 0.30, but cumulatively very high when the food items were grouped. However, the general observation was that no high selectivity was exhibited for any particular food items, hence the opportunistic nature of feeding habits continued to be the case regardless of the zone.

Table 5.14 Selectivity indices (Lawlor index β) of 1+ species for their food items in Zone 1 of the Thames Estuary in the winter of 2001

	Diet selectivity index (Lawlow index -β)											
Food items/SP	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	0.11	0.11	0.11	0.09	0.09	0.07	0.11	0.05	0.03	0.11	0.07	0.02
Crangonids	0.11	0.03	0.00	0.00	0.05	0.19	0.00	0.08	0.00	0.27	0.24	0.03
Gammarids	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.08	0.07	0.09	0.09	0.07
Amphipods	0.07	0.07	0.06	0.06	0.10	0.06	0.10	0.10	0.10	0.10	0.10	0.10
Copepods	0.12	0.10	0.02	0.02	0.11	0.08	0.08	0.12	0.10	0.12	0.12	0.00
Isopods	0.11	0.00	0.06	0.07	0.10	0.14	0.13	0.10	0.06	0.07	0.14	0.04
Cyprid larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terestrial insects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.09	0.15	0.15	0.08	0.15	0.15	0.00	0.08	0.00	0.00	0.00	0.14
Water weeds	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00
Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Silt	0.04	0.00	0.00	0.00	0.04	0.09	0.00	0.30	0.43	0.00	0.00	0.09
Oligochaetes	0.02	0.11	0.11	0.11	0.11	0.11	0.11	0.08	0.11	0.00	0.03	0.08
Chironomids	0.09	0.06	0.12	0.09	0.12	0.12	0.12	0.12	0.07	0.00	0.01	0.09
Polychaetes	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.17	0.00	0.00	0.00	0.67
Gastropods	0.04	0.00	0.12	0.08	0.12	0.06	0.08	0.20	0.12	0.00	0.00	0.20
Perch/fry	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Smelt/fry	0.00	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.00
Bleak/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Roach/fry	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Mullet/fry	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Flounder/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Dace/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Goby/fry	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.40	0.40	0.00	0.00	0.00
Stickleback/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
Bass/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream;
FL = flounder; 3SB = Three-spined stickleback; SM = Smelt;
SBA = Sea bass; and MU = Mullet

Real shifts in diet were apparent in winter with all species selecting crustaceans of all sizes. In addition eel and sticklebacks selected winter fish fry. The selectivity index ranged from 0.00-1.00 in Zone 1 in winter, but there were disappearances of fish in the in gut contents of perch, smelt and sea bass. Unexpectedly high values of β (1.0) were observed with respect to the selection of winter fish fry by eels and stickleback. However, because the high values of β stemmed from an absence of fry in other species it is apparent that most of the fish capture that took place was due to occasional encounter of fish prey. Oligochaetes were selected by all species but smelt.

Table 5.15 Selectivity indexes (Lawlor index β) of 1+ fish and their food items in Zone 2 the Thames Estuary in the winter of 2001

	Diet selectivity index (Lawlor index - β)											
Food items/SP	**PER**	**DA**	**RO**	**CGB**	**GU**	**EEL**	**BR**	**FL**	**3SB**	**SM**	**SBA**	**MU**
Branchiopods	0.11	0.11	0.11	0.11	0.11	0.02	0.11	0.02	0.11	0.11	0.07	0.01
Crangonids	0.20	0.00	0.00	0.00	0.08	0.20	0.04	0.06	0.00	0.20	0.20	0.00
Gammarids	0.11	0.05	0.11	0.02	0.11	0.11	0.11	0.11	0.02	0.11	0.11	0.04
Amphipods	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.01
Copepods	0.11	0.00	0.11	0.11	0.10	0.00	0.11	0.11	0.11	0.11	0.11	0.00
Isopods	0.04	0.00	0.00	0.02	0.14	0.20	0.18	0.00	0.04	0.20	0.20	0.00
Cyprid larvae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Terestrial insects	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Detritus	0.08	0.13	0.13	0.13	0.13	0.13	0.00	0.13	0.00	0.00	0.00	0.13
Water weeds	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Algae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Silt	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.20	0.20	0.00	0.00	0.20
Oligochaetes	0.00	0.12	0.12	0.12	0.12	0.02	0.12	0.12	0.12	0.00	0.01	0.12
Chironomids	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polychaetes	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
Gastropods	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Perch/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Smelt/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bleak/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Roach/fry	0.19	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.27	0.27	0.00
Mullet/fry	0.21	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.26	0.26	0.00
Flounder/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dace/fry	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Goby/fry	0.26	0.00	0.00	0.00	0.03	0.13	0.00	0.03	0.00	0.32	0.23	0.00
Stickleback/fry	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Bass/fry	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PER = perch; DA = dace; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream;
FL = flounder; 3SB = Three-spined stickleback; SM = Smelt;
SBA = Sea bass; and MU = Mullet

Like in Zone 1 crustaceans were the main food items selected in winter by all species especially larger groups. Oligochaetes were widely selected by most of the fish species. Unlike Zone 1, in Zone 2 perch, eel, smelt and sea bass successfully selected fish.

5.5.2 Cluster analysis of variables (Fish species) and observations (food items)

From the above detailed descriptions of fish diet with respect to age, zone and season it was apparent that there was considerable overlap in the food items taken by different fish species. In order to further explore in detail the associations between the diets of the 12 selected fish species, Cluster analysis was carried out using Minitab 13 for Windows software (Minitab, Inc. 2001) by an agglomerative hierarchical clustering of variables and observations routine using a complete linkage algorithm.

The results of the graphical analysis are displayed in a series of dendrograms in Figures 5.1 to 5.12. The results of the cluster analyses were presented for each of the various age groups, zones and seasons in two dendrograms, one for the % similarity relationship of different fish species in relation to the food they consume and one for the association of food items consumed. The clusters in each dendrogram were then compared to show how different food groups were selected by different species group

0+ fish and diet in summer

Figure 5.1 A dendrogram showing the % similarity relationship of 0+ year class fish in Zone 1 in the summer of 2001 based on type of food consumed

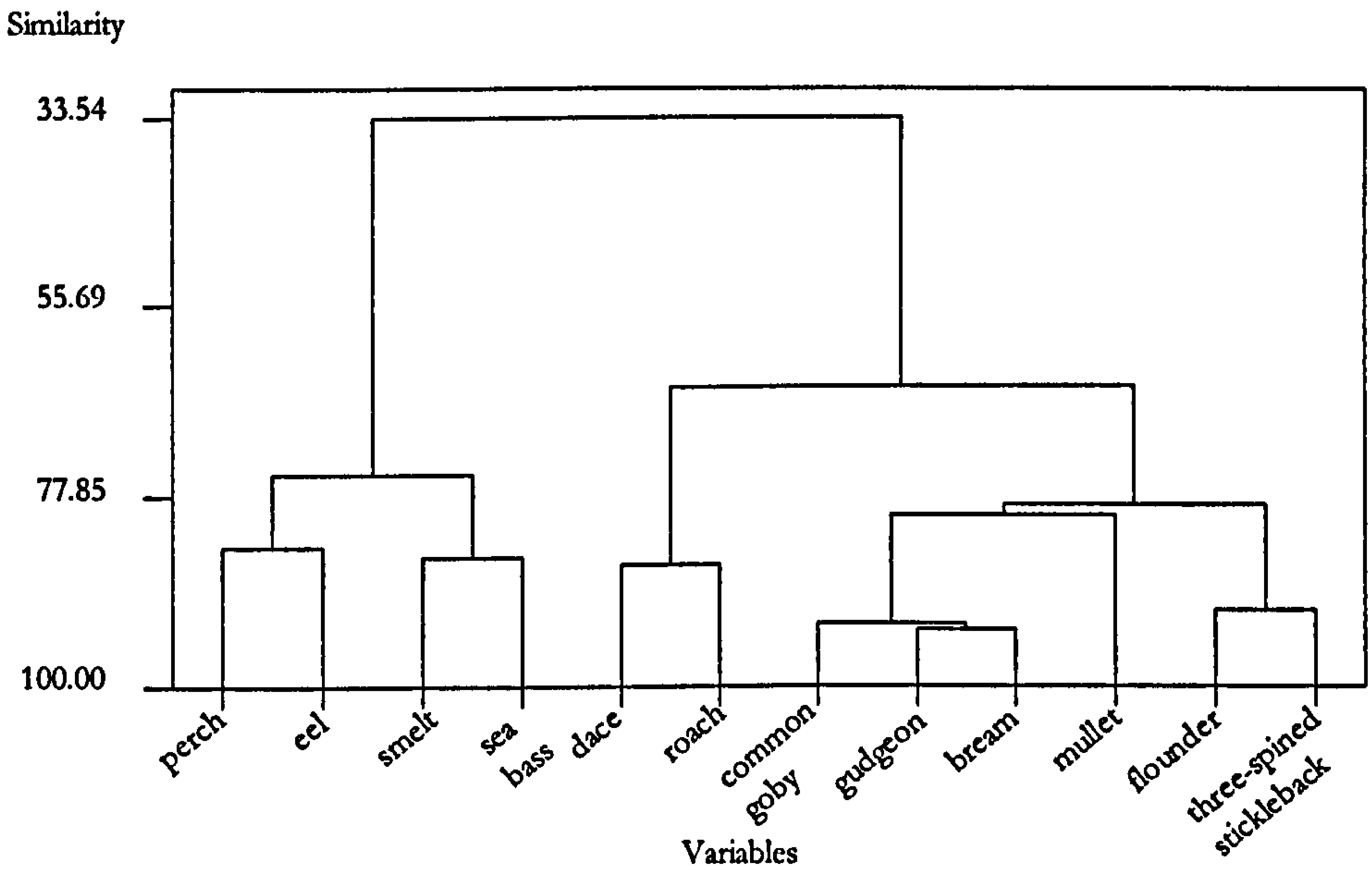


Figure 5.1 shows 3 distinct fish clusters based on the type of food consumed by 0+ fish in Zone 1 in summer namely:

Cluster 1: perch, eel, smelt and sea bass.

Cluster 2: dace and roach

Cluster 3: common goby, gudgeon, bream, mullet, flounder and three-spined stickleback.

Cluster 1 represents the predominantly carnivorous/cannibalistic species.

Cluster 2 represents the predominantly plankton/plant/algae feeding species

Cluster 3 represents the predominantly bottom feeding species

Figure 5.2 A dendrogram showing the association of food items (food groups) consumed by 0+ in the summer of 2001

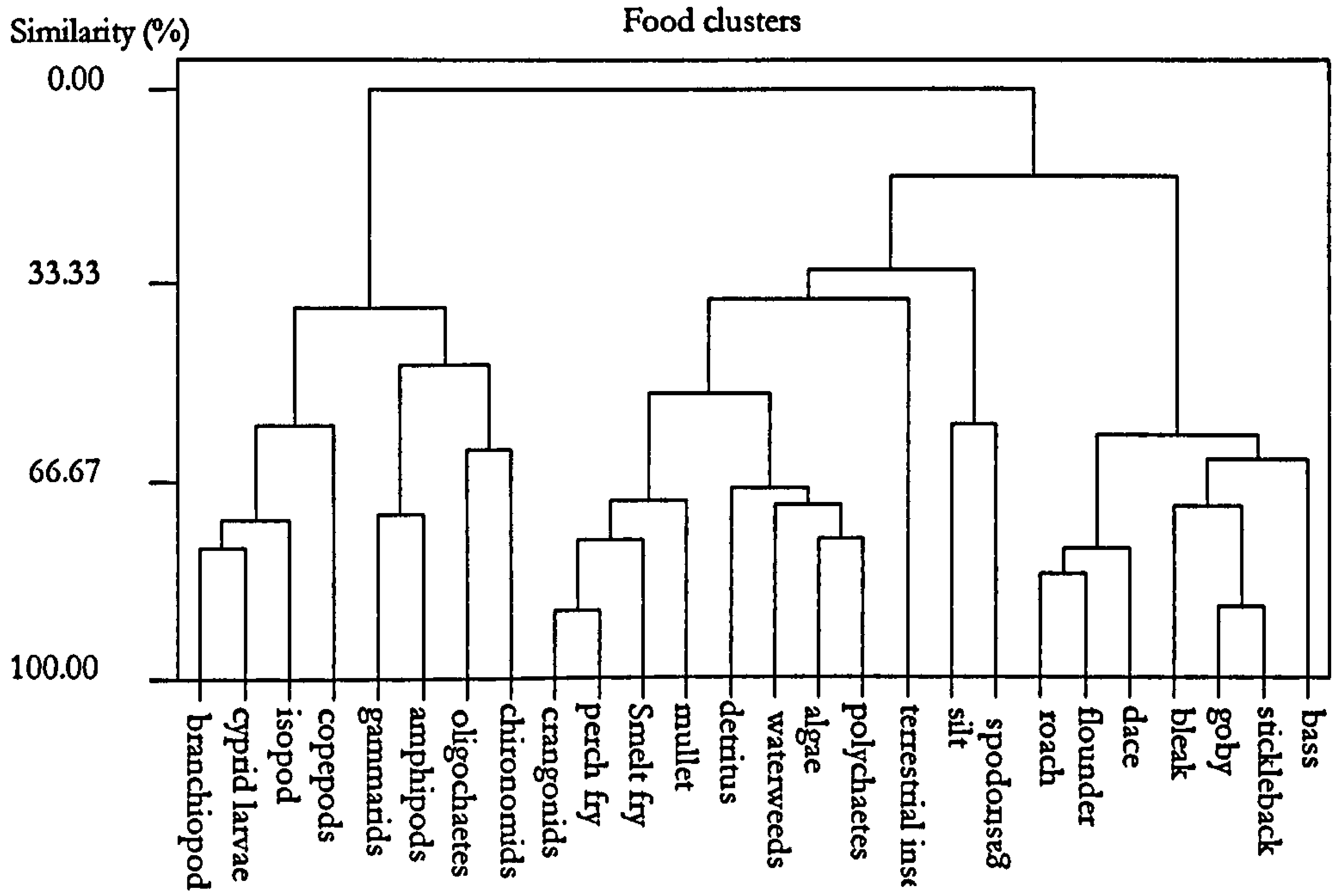


Figure 5.2 shows that the food items separated into three main clusters of food items consumed by 0+ fish namely:

<u>Cluster A</u>

Crustaceans, oligochaetes, and chironomids

<u>Cluster B</u>

Mixed fish fry, detritus, silt, polychaetes, terrestrial insects, algae and water weeds.

<u>Cluster C</u>

Fish fry except Perch, smelt and Mullet

Fish Cluster 1 was strongly associated with food Clusters C and B. Fish Cluster 2 was strongly associated with food Cluster B and the whole of fish Cluster A. Fish Cluster 3 was strongly associated with all food clusters. These were omnivorous estuarine group of fish who opportunistically consumed fish which were not actually their main diet.

Figure 5.3 A dendrogram showing the % similarity relationship of 0+ year class fish in Zone 2 in the winter of 2001 based on type of food consumed

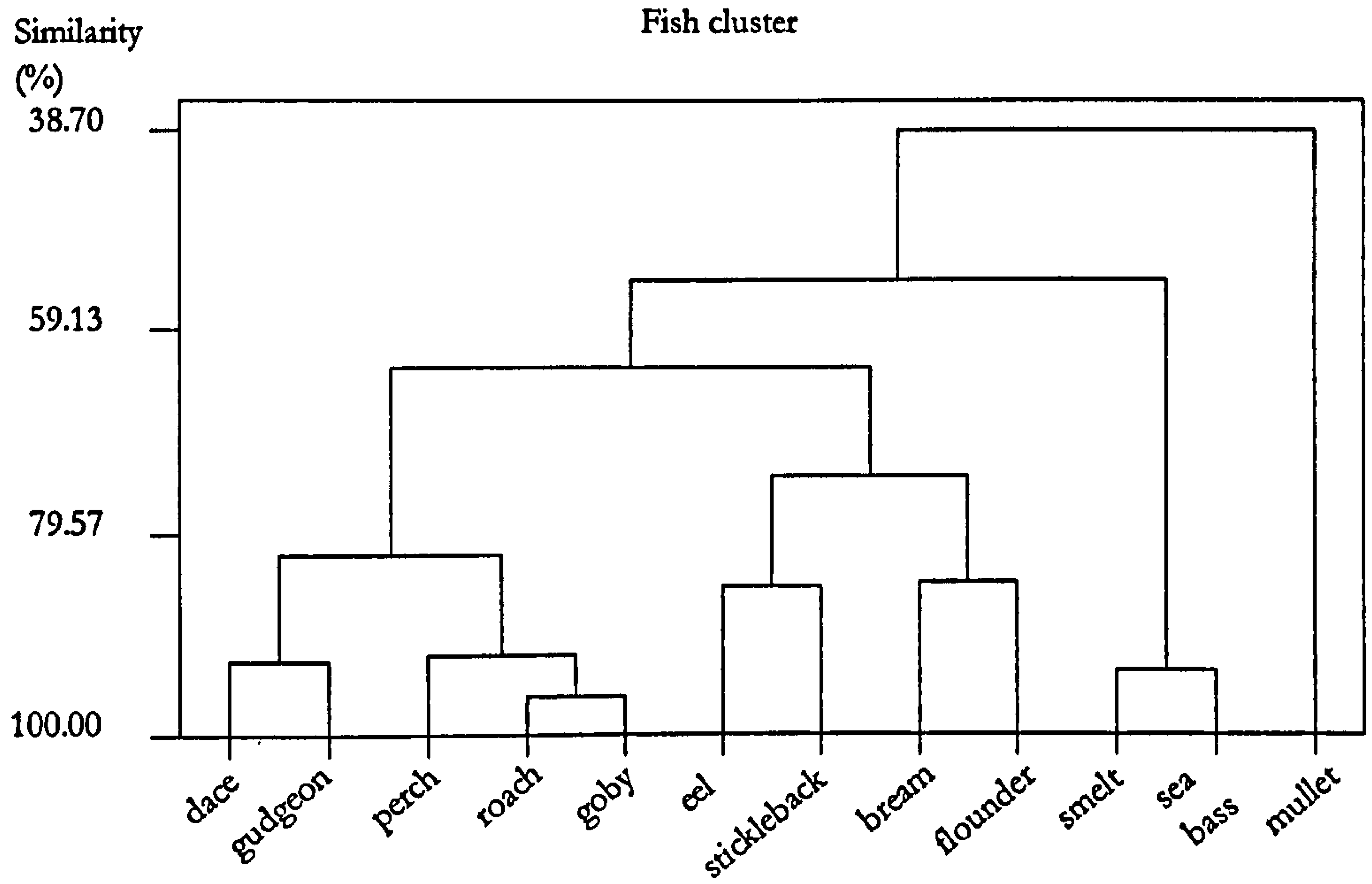


Figure 5.3 shows 4 fish clusters based on the type of food consumed by 0+ fish in Zone 2 in winter

Fish Cluster 1: perch, roach, dace, gudgeon and common goby

Fish Cluster 2: eel three-spined stickleback, bream and flounder

Fish Cluster 3: smelt and sea bass

Fish Cluster 4: mullet

Figure 5.4 A dendrogram showing the association of food items (food group) consumed by 0+ fish in the winter of 2001 in Zone 2

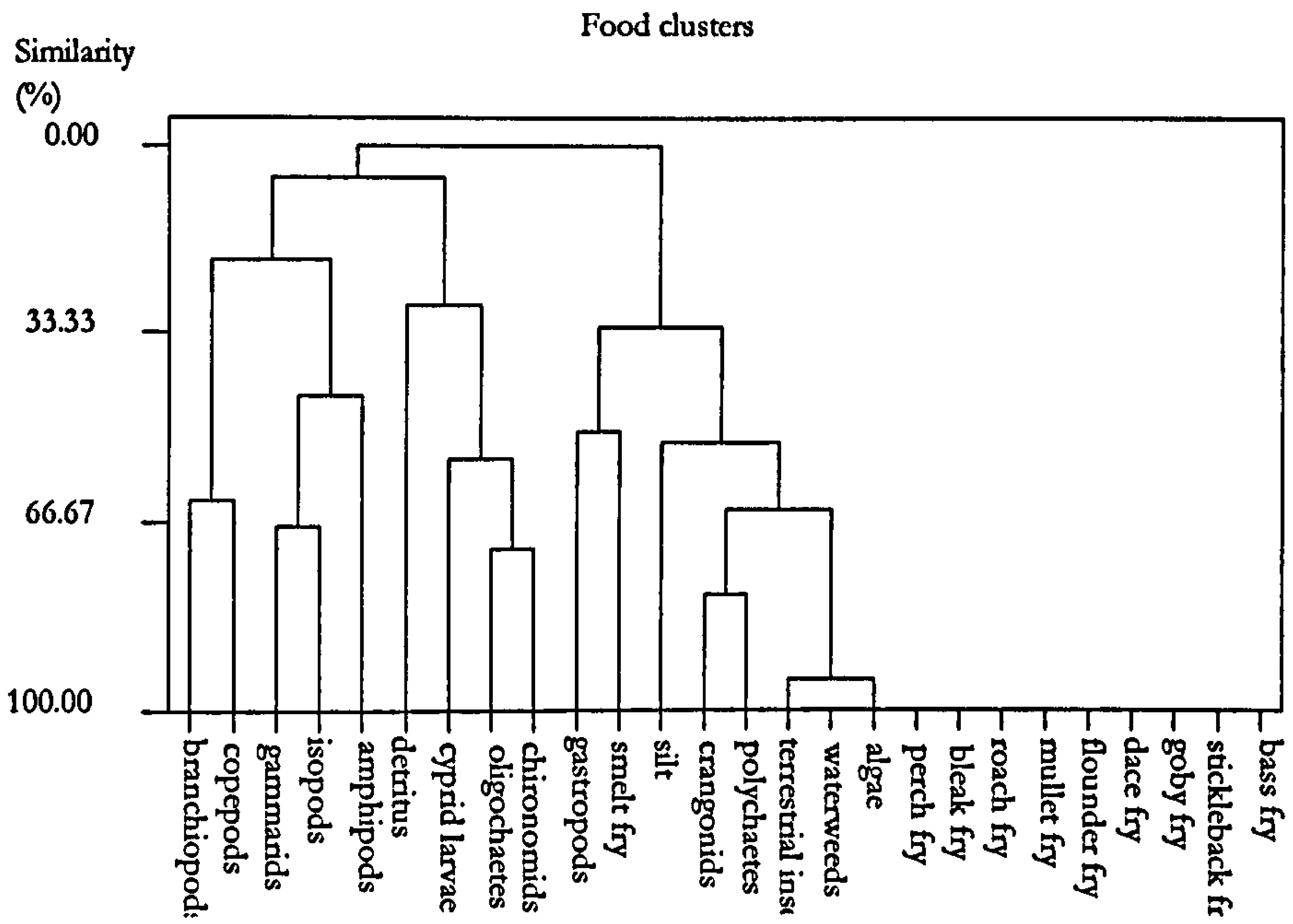


Figure 5.4 shows that the food items of 0+ fish in Zone 2 during summer fell into three major Clusters namely:

<u>Food Cluster A:</u> crustaceans except cyprid larvae and crangonids

<u>Food Cluster B:</u> oligochaetes, chironomids, cyprid larvae and detritus

<u>Food cluster C:</u> smelt fry, crangonids, polychaetes, terrestrial insects and algae and silt

Fish Cluster 1 (perch, roach, dace, gudgeon and goby) was strongly associated with Food Clusters A and B. Differences between the species were small. Dace and gudgeon did not consume gastropods, roach and goby took terrestrial insects and perch took smelt. Fish Cluster 2 (Eel, 3-spined Stickleback, Bream and Flounder) - this group was strongly associated with Food clusters A and B but all species had also taken a number of food items from food Group C particularly smelt fry which were taken by Eel, Flounder and Sticklebacks. Polychaetes which were eaten by eels, bream and flounder and crangonids eaten by eels and flounder

Fish Cluster 3 smelt and sea bass)

This group was strongly associated with Food Cluster A with Sea bass also slightly associated with Food Cluster C as they consumed Polychaetes and smelt fry. The diet of these fish seemed very restricted as no Group B food items were consumed.

Fish Cluster 4 (mullet)

This group was associated with food groups A, B and C but not strongly as only 4 types of food were taken in total and only 2 if one excludes detritus and silt which were the predominant items recorded in the diet.

5.5.3 Overview of clustering for 0+ fish in summer

In Zone 1 the presence of fish fry during the summer was an important element in the diet of many fish and this was noticeably absent apart from occasional smelt from the diet of fish in Zone 2. Generally the 0+ fry in Zone 1 had a broader diet than the same fish in Zone 2 suggesting that conditions for the majority of fish fry species were more favourable in Zone 1.

1+ fish and diet Summer

Figure 5.5 A dendrogram showing the % similarity relationship of 1+ year class fish in Zone 1 in the summer of 2001 based on types of food consumed

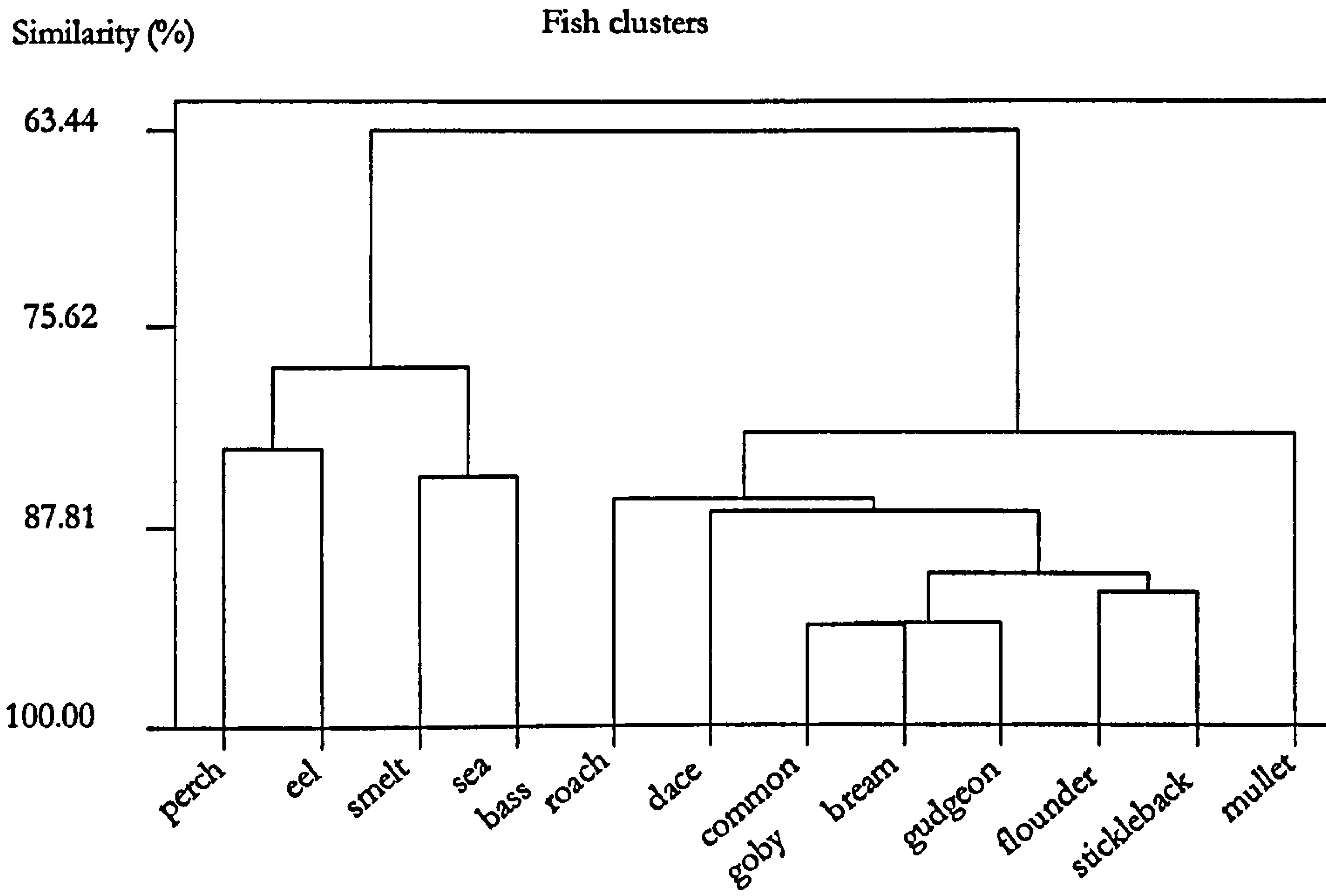


Figure 5.5 shows 4 distinct fish clusters based on the type of food consumed by 1+ fish in Zone 1 in summer namely:

Cluster 1 perch, eel, smelt and sea bass

Cluster 2 flounder and three-spined stickleback

Cluster 3 dace and roach

Cluster 4 goby, gudgeon and bream

Figure 5.6 A dendrogram showing the association of food items (food groups) consumed by 1+ fish in the summer of 2001 in Zone 1

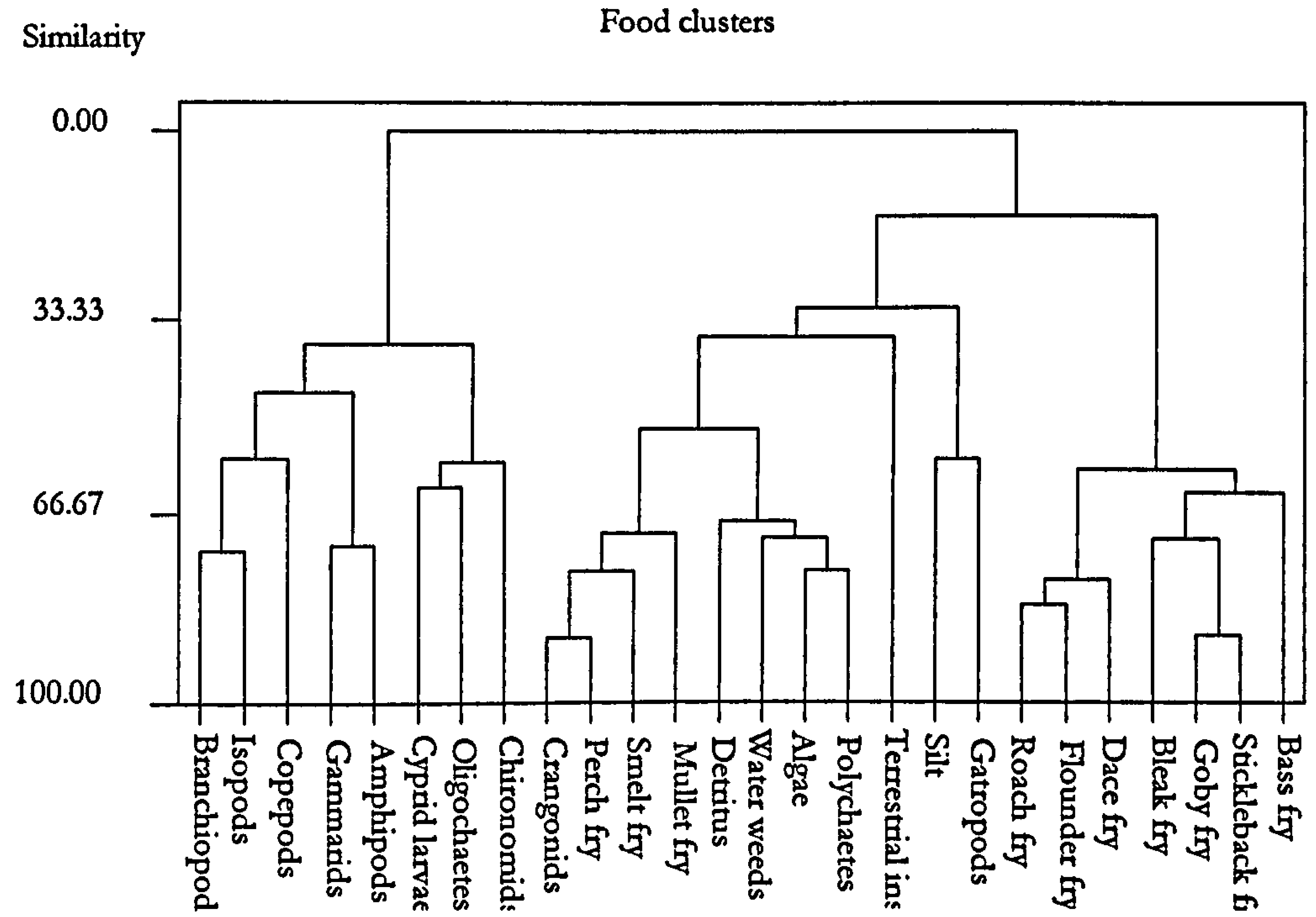


Figure 5.6 shows 4 distinct fish clusters based on their association as food items for 1+ fish in Zone 1 in summer namely:

Food Cluster A sea bass fry, stickleback fry, goby fry, dace fry, flounder fry, bleak fry, terrestrial insects, water weeds and algae

Food Cluster B branchiopods, roach fry, gastropods, mullet fry, and smelt fry

Food Cluster C, copepods, chironomids, cyprid larvae, silt, oligochaetes, detritus, crangonids, isopod and polychaetes

Food Cluster D gammarids and amphipods

Fish Cluster 1 (smelt, sea bass, perch and stickleback) were the primary piscivores feeding extensively on fish fry (over 20%) from Food Clusters A and B.

Fish Cluster 2 (eel, flounder and mullet) were characterised by taking Food Cluster C including detritus, cyprid larvae, oligochaetes and polychaetes. They were clearly feeding on muddy shore benthos. Eels and flounder also took amphipods from food Cluster D

Fish Cluster 3 (Dace and Roach) consumed food mainly from Food Cluster D and the non-fish members of food group A (terrestrial insects, water weeds and algae). It appeared that these fish were foraging amongst water weeds and fed both on the benthos and at the surface.

Fish Cluster 4 goby, gudgeon and bream consumed food mainly from food clusters C, particularly oligochaetes and D, goby and gudgeon took in a lot of detritus and silt.

Figure 5.7 A dendrogram showing the % similarity relation ship of 1+ year class fish in Zone 2 in the summer of 2001 based on type of food consumed

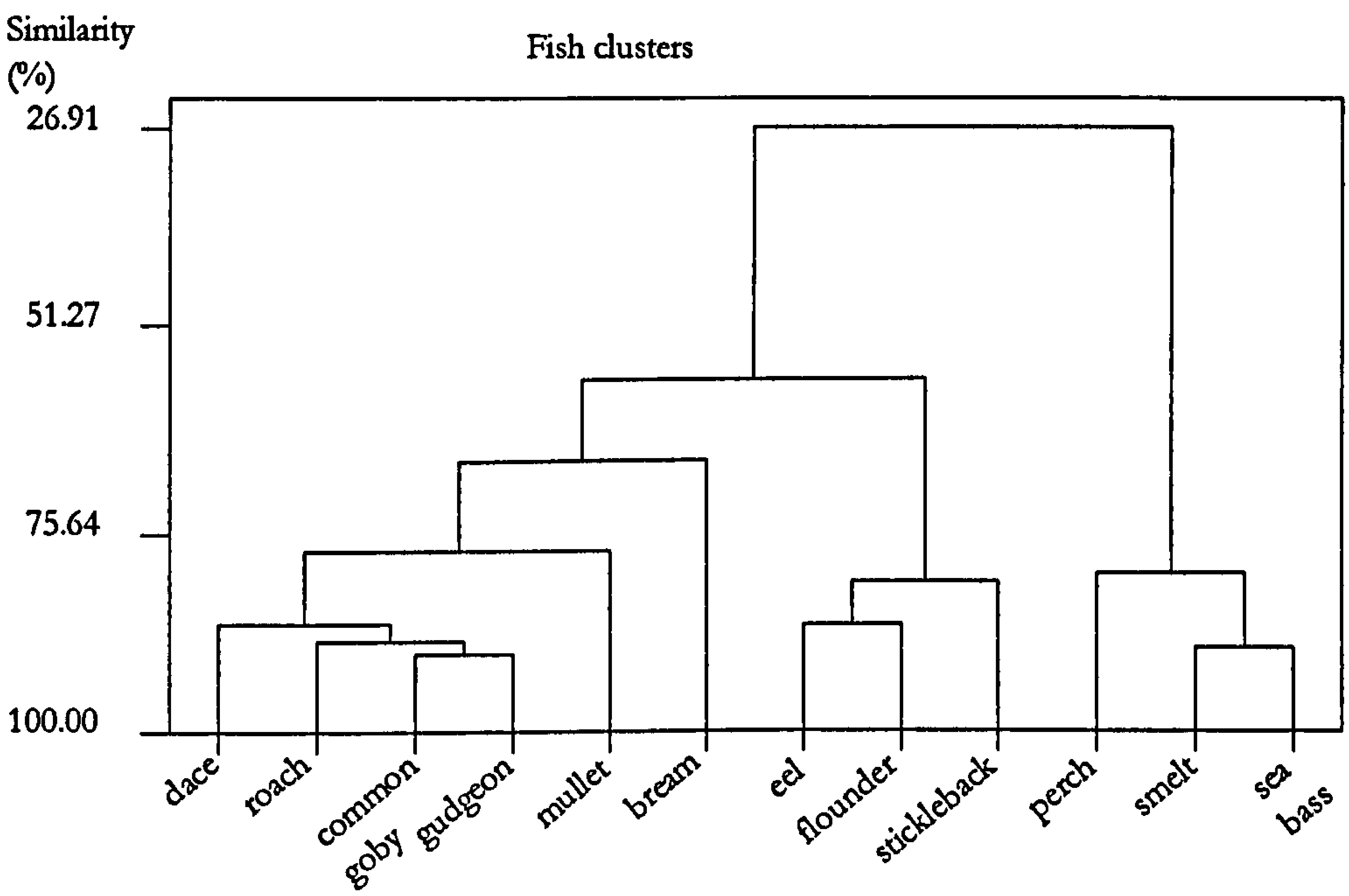


Figure 5.7 shows 4 distinct fish clusters based on type of food consumed by 1+ fish in Zone 2 in summer namely:

Fish Cluster 1 dace, roach, goby, and gudgeon.

Fish Cluster 2 mullet and bream

Fish Cluster 3 eel, flounder and stickleback

Fish Cluster 4 perch, smelt and sea bass

Figure 5.8 A dendrogram showing the association of food items (food groups) consumed by 1+ fish in the summer of 2001 in Zone 2

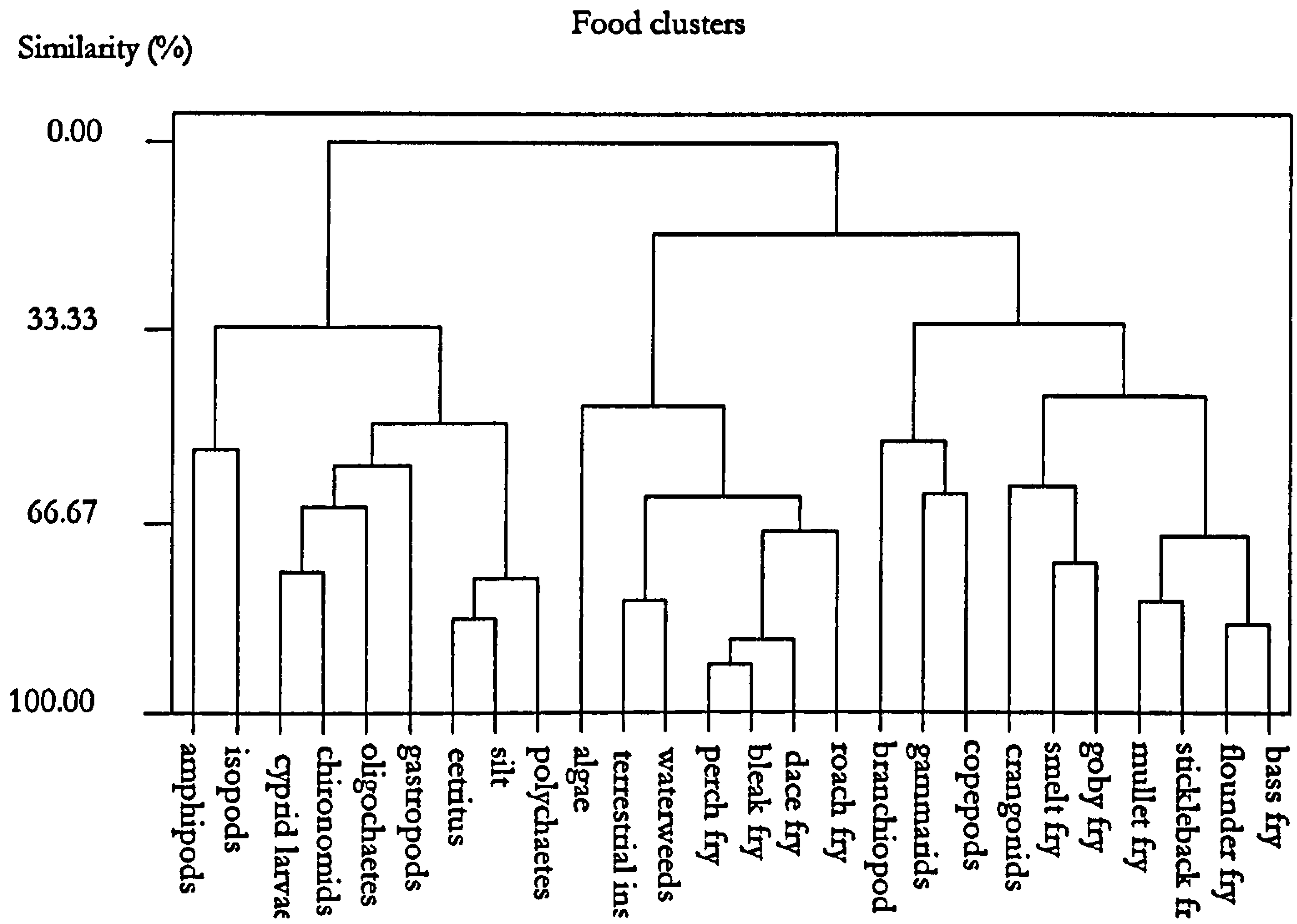


Figure 5.8 shows that the food items of 1+ fish in Zone 2 in summer fell into 4 main clusters namely:

Food Cluster A: Fish fry of all species, terrestrial insect and water weeds

Food Cluster B: crangonids

Food Cluster C: branchiopods, gammarids, copepods and algae

Food Cluster D: amphipods, isopods, cyprid larvae, chironomids, detritus, gastropods, oligochaetes and silt

Diet of Fish Cluster 1 (dace, roach, goby and gudgeon). This Cluster did not consume fish fry from food cluster A. They all consumed food items from Clusters B, C and D.

Diet of Fish Cluster 2 (bream and mullet)

Bream and mullet also consumed fish fry (smelt) from Food Cluster A but in very small amounts (3% and 7% respectively). Both species also consumed algae. The diet of bream was broader than mullet which consumed relatively few crustacean food types of Food Cluster C and D and no crangonids.

Diet of Fish Cluster 3 (eel, flounder and stickleback). This group also Fed on the fish fry of food cluster A but to a lesser extent (12% in Flounder and >30% in eels and stickleback). Each of these species took a broad diet including most food types within food clusters B, C and D.

Diet of Fish Cluster 4 (perch, smelt and sea bass) fed on the fish fry of Food Cluster A. The frequency of occurrence of fish in the diet of this group is 45%. They also all fed on all the Crustacean food types of Cluster C and D but not on gastropods and only infrequently on oligochaetes and Chironomids.

1+ fish and diet winter

Figure 5.9 A dendrogram showing the % similarity relationship of 1+ year class fish in Zone 1 in winter 2001

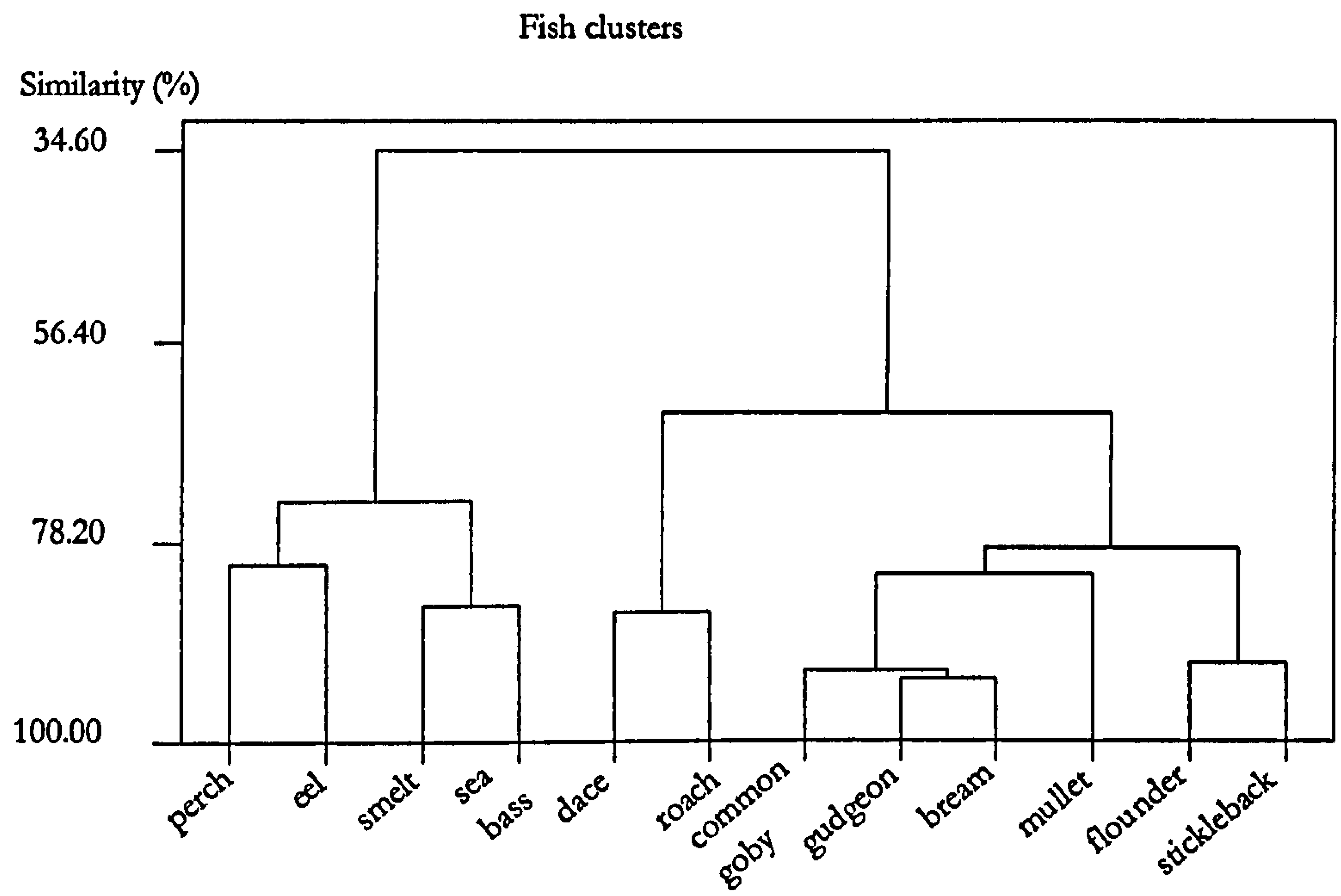


Figure 5.9 shows 4 distinct clusters based on the type of food consumed by 1+ fish in Zone 1 in winter namely:

<u>Fish Cluster 1</u> perch, eel, smelt and sea bass

<u>Fish Cluster 2</u> dace and roach

<u>Fish Cluster 3</u> goby, gudgeon, bream and mullet

<u>Fish Cluster 4</u> flounder and three-spined stickleback

Figure 5.10 A dendrogram showing the association of food items (food groups) consumed by 1+ fish in the winter of 2001 in Zone 1

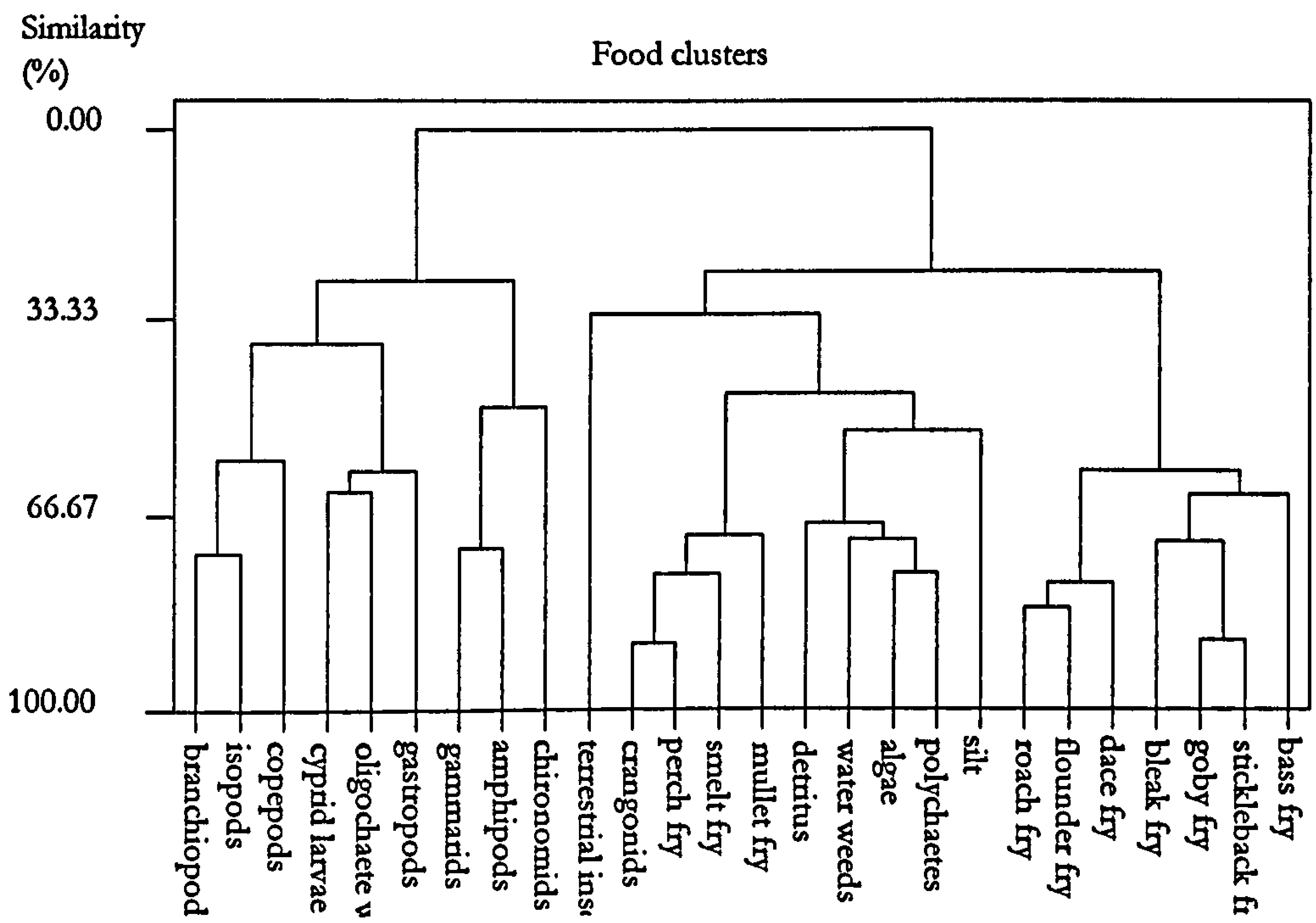


Figure 5.10 shows that the food items of 1+ fish in Zone 1 in winter separated into 5 main clusters namely:

Food Cluster A: bass fry stickleback fry, goby fry, bleak fry , flounder fry, roach fry

Food cluster B: detritus, water weeds, algae, polychaetes and Silt

Food cluster C: crangonids, perch fry, smelt fry and mullet fry

Food Cluster D: branchiopods isopods copepods cyprid larvae oligochaetes gastropods

Food Cluster E: gammarids, amphipods and chironomids.

Diet of Fish Cluster 1 (perch, eel, smelt and sea bass) All the fish from this cluster fed on clusters C, D an E primarily on the crustacean members of the Clusters. Perch also fed extensively on Cluster B. eels also fed on Cluster A but the other usually piscivorous species did not forage on fish in winter in this Zone.

Diet of Fish Cluster 2 (dace and roach): The two species fed primarily on focd cluster D and E. Very few items were recorded from any of the other Food clusters apart from Detritus in Food Cluster B.

<u>Diet of Fish Cluster 3</u> (goby, gudgeon, bream and mullet) the fish in this group fed mainly on food Clusters D and E although gudgeon did consume the occasional fish (2%) and crangonids and some detritus was taken by all except bream.

Diet of fish Cluster 4 Flounder and 3 spined stickleback: This fish Cluster fed primarily on Food Groups D and E but also took fish in relatively small numbers from Food Cluster A and flounder took occasional items from Food Group B.

Figure 5.11 A dendrogram showing the % similarity relationship of 1+ year class fish in Zone 2 in the winter of 2001 based on type of food consumed

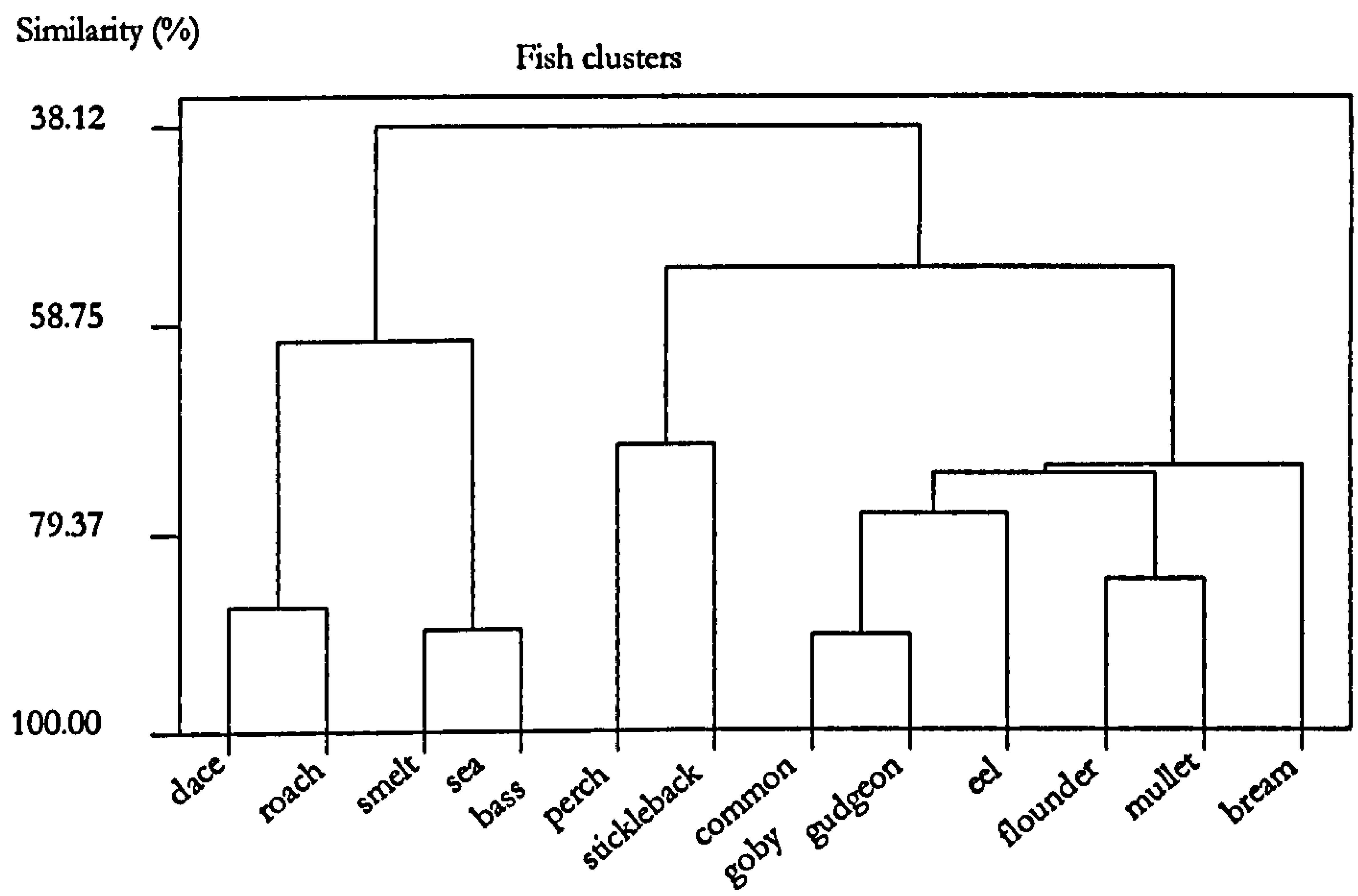


Figure 5.11 shows 4 distinct fish clusters based on the type of food consumed by 1+ fish in Zone 2 in winter namely:

<u>Fish Cluster 1</u> dace and roach

<u>Fish Cluster 2</u> smelt and sea bass

<u>Fish Cluster 3</u> perch and stickleback

<u>Fish Cluster 4</u> common goby, gudgeon, eel, flounder, mullet and bream

Figure 5.12 A dendrogram showing the association of food items (food groups) consumed by 1+ fish in the winter of 2001 in Zone 2

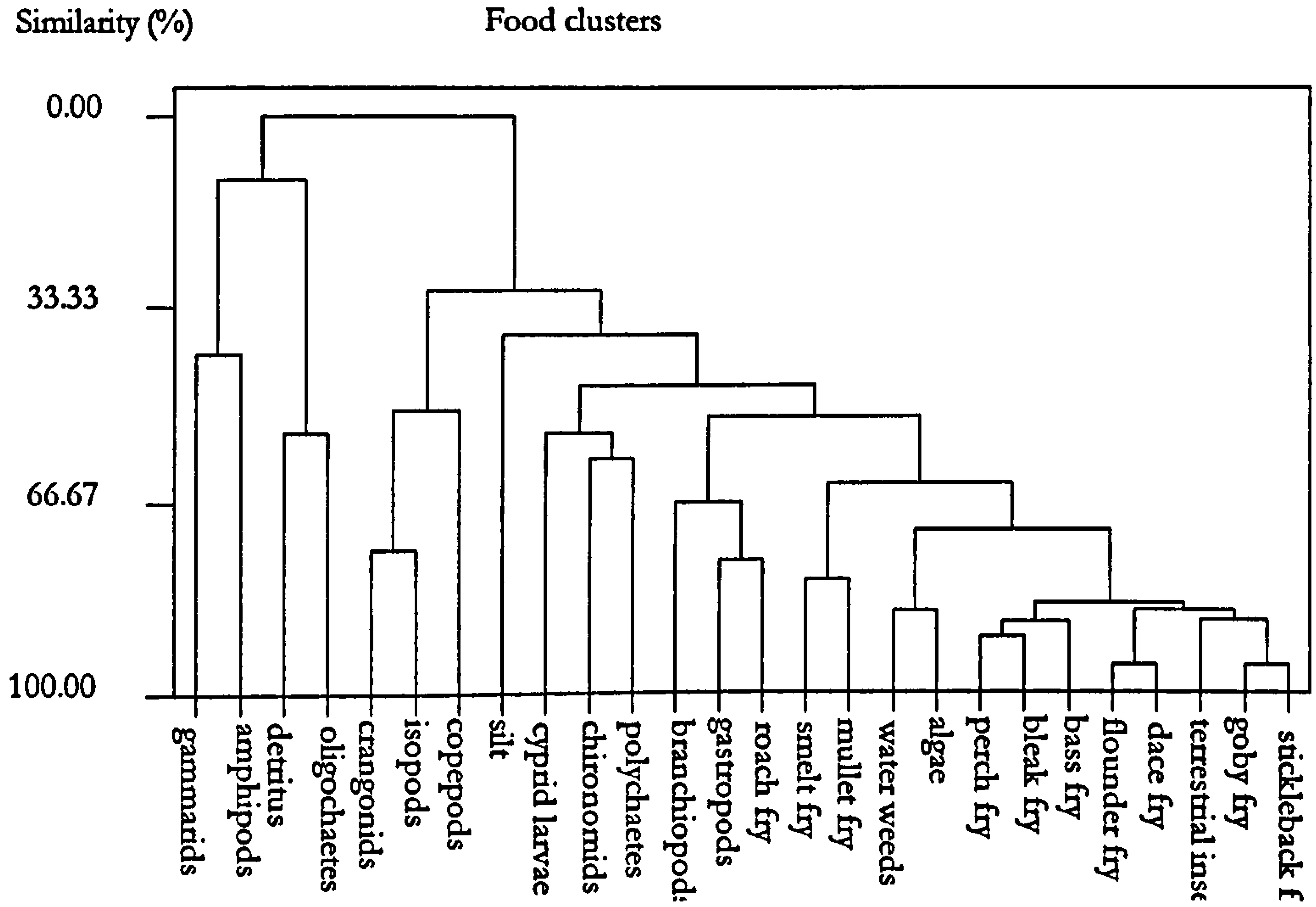


Figure 5.12 shows that the food items of 1+ fish in winter in Zone 2 separated into 6 main clusters namely.

<u>Food cluster A</u> goby fry, stickleback fry, dace fry, flounder fry, bass fry, bleak fry, mullet fry and smelt fry

<u>Food cluster B</u> roach fry and branchiopods

<u>Food Cluster C</u> Silt

<u>Food Cluster D</u> crangonids isopods copepods

<u>Food Cluster</u> E Amphipods, Gammarids Detritus Oligochaetes

<u>Diet of Fish Cluster 1</u> (Dace and Roach): this group fed on Food Cluster E plus branchiopods (Cluster B). Dace also took copepods from Cluster D.

<u>Diet of Fish Cluster 2</u> (Smelt and Sea Bass)

Smelt and Sea Bass maintained a strongly piscivorous diet with approximately one third of the food items taken belonging to Food Cluster A and B. Other important food cluster from these two species were clusters D and E which made up the rest of the diet

Diet of Fish Cluster 3 (perch and stickleback) The two species fed primarily on the Crustacea of Food Groups, D and E. Perch also fed on the fish from Food Groups A and B.

Diet of Fish Cluster 4 (goby, gudgeon, eel, flounder, mullet and bream): All the fish in this cluster fed extensively on Food Group E and all except Mullet also fed of Food Group D. Group C (silt) was found in the guts of gudgeon, eels, flounder and mullet but not in goby or bream. All the fish in this group took branchiopods.

5.5.4 Overview of Diet of 1+ Fish

There are several features which stand out from the data presented which can be summarised here. Firstly, all fish species in all zones and both seasons overlapped to a lesser or greater extent. At the same time each species had some special features of its diet which distinguished it from its competitors. The diversity of food types taken also varied between species, zone and seasons with the widest diversity taken by piscivorous fish in Zone 1 in summer and the narrowest by mullet in Zone 2 in winter. Zone 1 in summer appears to offer the most varied and rich feeding grounds with abundant 'Crustacea', 'Other' and 'Fish' food items. In winter in Zone 2, in particular, there appeared to be a severe reduction in the availability of fish larvae and 'Other' items also appeared less available and most fish relied very extensively on 'Crustacea'.

5.6 Discussion

This study focused on the complex issues of the influence of ontogeny, time (season) and space on the diet of 12 fish species using the Thames Estuary for feeding. The diet of the 12 fish species studied was shown to have a wide spectrum. It has also been shown that species that reside in the Thames Estuary do not have highly specialised diets supporting the observations of Edgar and Shaw (1998) on the general feeding behaviour of estuarine fish, and being generally carnivorous and opportunistic supporting the observations of Alberet (1994). The gut contents study revealed that the individuals used the food resources in somewhat differently depending on whether they were in Zone 1 or 2 of the estuary. Two explanations for this could be proposed. Firstly, that some items are more abundant and others were actually exclusive for one of the environments (terrestrial insects in Zone 1) and this is because of the varying availability of food, its consumption also differed. Secondly, that it was common for there to be changes in the gut contents according to age group as well as the time of the year.

Researchers have been criticised for a failure to resolve biomass, sizes of food items and predatory fish issues to the highest possible level of accuracy (Cohen *et al.*, 2003) but increasing attributes to measure in a single study involves a considerable increase in the effort and time required (Thompson and Townsend, 2000). A related issue is the standardisation of taxonomic resolution of living food items within a food group (e.g. branchiopods, gammarids, crangonids, terrestrial insects etc are lumped classifications). Published gut contents studies vary in the methodology used, the season of sampling, the criteria for defining a food group and the level of taxonomic resolution of the prey items. Some of these factors have now been convincingly shown to affect estimate of food consumption properties (Cohen *et al.*, 1990).

There was an extensive overlap of the diet of all the fish examined regardless of ontogeny with very little selectivity for food items (see section 5.3.7 page - 195 - and Tables 5.10 to 5.15; pages - 224 -to- 229 -). Similar observations on Thames fish diets include those of Huddart and Arthur (1971) Sedgwick (1978), Wheeler (1979), Naismith and Knight (1988), Jarrah (1992), Hutchinson and Hawkins (1993) and Chen (1994). In other British estuaries they have included Ascroft (1900), Hartley (1940), Moore and Moore (1976), Kartar (1977), Parsons (1978), Summers (1979, 1980) Beaumont and Mann (1984).

All of these studies employed gut contents analysis. This technique allows determination only of presence or absence of items in the diets. Some have attempted this successfully. Other techniques combine quantitative feeding observations (i.e. where feeding behaviours are precisely timed) and faecal analysis Bowen (1983). An assessment of diets using qualitative feeding observations may not be indicative of feeding preferences unless large numbers of such observations are obtained. Faecal and gut contents analyses do allow quantification of the arthropods ingested but not of exudates, which leave no trace. Feeding observations also have associated challenges which are outlined in following paragraphs.

Through gut contents analysis much information has been gained about the feeding habits of the most common fish in the Thames Estuary, but there are cautionary notes to be considered about this methodology. First, for most estuarine consumers, gut contents will underestimate both the biomass consumed as well as the variety of components, since some diet items may be unrecognised, or only soft parts may be ingested. Thus this approach provides a minimum estimate of the diet of a fish consumer. Second, consumer diets have been observed to change dramatically with seasonal availability of food and ontogeny, requiring a long term and comprehensive study to fully characterise consumer diet items. Third, many fish consumers (e.g. flounder, eel, mullet, bream and gudgeon) ingest material that is difficult to identify. It is inevitable therefore that an analysis of gut contents will result in a diet category labelled "Other" or "detritus" or both. Fourth, important food categories may be overlooked. For example, fungi, bacteria associated with detritus and plant debris may be extremely important numerically and nutritionally. Many fish, e.g. perch, sea bass, and the smelt swallow their prey whole. In these cases, examination of gut content provides a good indication of the items consumed, but unless digestion rate is determined and size of prey measured (Bowen, 1983), these data do not quantify the actual linkages between a predator and its prey community. However, even within these constraints, gut analysis has been used to construct species diet matrices that contain much information that is of great value for qualitative description and analysis.

This study confirms previous studies that suggest that food resources are not in shortfall in the Thames Estuary. In an unpublished report, The Benthic Ecology Group, BEG (1994) estimated that, for the Thames Estuary, excluding oligochaetes a benthic invertebrate density of about 430 individuals m^{-2} is available for food use by the fishes in summer. Huddart (1971a) first noted the importance of aquatic invertebrates as a major food source for fishes inhabiting the Thames Estuary. The current study has confirmed the high contribution of oligochaete, polychaete, gastropod, macro and micro-crustaceans to the diet of Thames Estuary fish. The current study has also highlighted the importance of fish fry as a food source for species such as eel, smelt bass and perch.

'Crustaceans' were found to be the major dietary items of both 0+ and 1+ fish in all seasons and locations. For perch, sea bass and smelt, 'Fish' are the second major food source, their consumption limited only by the size of the consumer and availability of the resource. Huddart and Arthur (1971) and Sedgwick (1978) employed gut analysis to conclude that crustaceans, especially the gammarids were the main diet of fish in Thames Estuary at that time. The contribution of fish to the diet of fish was not made apparent. This is probably a function of availability during the early period of the Thames Estuary recovery. The high occurrences of planktonic crustaceans (branchiopods and cyprid larvae), and macrobenthic crustaceans (corophids, amphipods, crangonids, gammarids, copepods and mycids), in the upper and middle estuary in the stomachs of most fish species examined could be one of the reasons for the coexistence of different fish species in the estuary. This is demonstrated by the very high diet overlaps between all species examined (Tables 5.4 to 5.9) and the low selectivity indexes (Tables 5.10 to 5.15) 'Crustacea' can be assumed to be of high nutritional value and an important protein source for juvenile fish. In the Thames estuary 'Crustacea' exist both in the pelagic and benthic environment. The pelagic group, are mainly the planktonic (branchiopods and cyprid larvae). The benthic types are the gammarids, amphipods, crangonids and *Asellus sp.* These are found beneath gravel, sands and stones/rocks. Fish pick benthic Crustacea principally by moving loose gravel or stones or by snatching freely moving ones (Horn and Gibson, 1988). Loose gravel, sand and stones in the upper estuary are important substrates, rich in gammarid and amphipod crustaceans. The present study demonstrates that apart from oligochaetes species gammarids account for the largest assemblage of benthic macroinvertebrate species in the upper estuary. The value of this resource is greater in winter as many gammarids, in particular *Gammarus zaddachi*, are more plentiful, substituting winter sensitive living food items such as terrestrial insects, fish fry etc. Andrews (1977) and Andrews *et al* (1992) observed on *Gammarus* species were a major food resource in the estuary.

At the same time there is temporal separation of peak abundance between the top three most numerous fish species. Habitat utilisation by different fish species is by no means uniform but depends very much upon the sizes of the fish, season and zone. Food overlap between fish species did not point to negative interactions.

The considerable variation in the categories of food items consumed (diet widths - α see Table 5.3; page - 219 -) by a species at a given zone or location demonstrates that diet composition of omnivorous and carnivorous fishes of the Thames Estuary is determined mostly by food availability. For example the data on the food habits of sea bass, *Dicentrarchus labrax*, smelt *Osmerus eperlanus*, perch *Perca fluviatilis* and flounder, *Platichthys flesus* Zone 2 show a very wide range of food taken although preferences become apparent during periods when food availability is diverse. Fish, gammarids and crangonids are in fact usually the main contents of the stomachs of adult sea bass and smelt in particular, because these species do not scavenge in sediments for benthic burrowers. But the proportion of food items under 'Other' food categories (detritus, polychaetes, gastropods, oligochaetes etc) varied and tends to increase in these piscivorous species when fish fry potential availability is low for example in all zones in winter or in zone 2 during summer

The diet of roach and dace in Zone 1 consists of a mixture of animal and plant materials. A significant proportion of these two fish species were found with some algae and water weed materials in their guts but whether these two species are significantly omnivorous in the sense of obtaining energy and nutrients from plants as well as animals is unknown. This needs further exploration and was beyond the scope of the present study. In Zone 2 neither roach nor dace appeared to consume plant materials. The reason for this spatial variation in plant consumption is unknown. What may influence algal or other plant material intake in Zone 2 may be the selective feeding from the plant community or turf. The type of algae and water weeds preferred may not be present or abundant in Zone 2 for reasons that may involve differences in the habitat. Some evidence exists to show that fishes select algae that are relatively rich in protein and easy to digest, Horn and Neighbors (1984). The reason advanced by these authors is that other algae appear to be avoided because they are tough or calcareous or because they contain secondary compounds that reduce palatability. In some cases, according to (Horn and Neighbors, 1984) a combination of factors operates to cause algae either to be chosen or avoided.

Although flounder were collected throughout the estuary the main diet of flounder is 'Crustaceans' (Frequency of occurrence, Oi = 54% winter and summer average) in Zone 1 whereas in Zone 2 'Other' food categories which constitute oligochaetes, polychaetes, detritus, silt and gastropod dominate the gut contents. This dominance is related to food availability which in turn is driven by the substrate types. Examination of all the data on the gut contents indicate that prey items are more diverse in summer, different sizes (planktonic and macrobenthic) of prey items are also more plentiful in numbers. There was however no difference between winter and summer potential food availability (difference in macroinvertebrate mean densities between summer and winter was not significant [($t_{(obs)}(14) = (0.75)$, at $P = 0.05$] (see chapter 3). There were however differences in potential food composition, for instance fish fry were generally absent in winter and abundant in summer, but gammarids were more abundant in winter than in the summer.

In summer the different prey items comprising fish fry, cyprid larvae, amphipods, etc are very abundant. In winter fish fry are scarce in both zones. Because of this change in food composition imposed by the winter season, fish eaters such as perch, smelt and sea bass shift to other food items such as planktonic and larger crustaceans. During the winter months, in Zones 1 and 2 the number of food types taken by many species is reduced, and this is particularly marked in Zone 2.

The contribution of the substrate characteristics towards gut contents of fish in the estuary is well demonstrated by this study. Gravel and stone substrates are widely distributed in the estuary, except in the Royal Albert and King George Basins. These substrate types are known to be good habitats for 'Crustacean' and some members of the 'Other' food categories especially gastropods. On the other hand, the majority of 'Other' food items particularly oligochaetes and polychaete worms are found in mud flats. Oligochaete worms burrow with their heads sticking out in the water column and polychaete worms completely in the mud (Barnes 1994). Therefore mud banks in the creeks and mud flats of the mid estuary are important habitats for these food sources. Fish that feed on polychaete and oligochaete worms often take the substrate and then either filter the food items or swallow the substrate so that the gut digests the contents. This probably explains for mullet, a benthic feeder silt/mud is the main component of its gut contents.

This study has demonstrated that changes in resource availability can lead to changes in a species' diet. However, these variations have been observed to occur in frequency or range of items consumed. Diet changes from summer to winter might be due to seasonal modifications in the invertebrate community (Andrews et *al*, 1992 and Atrill, 1998), i. e., resource availability is affected by its temporal and spatial distribution, (Martinez and Lawton, 1995). The majority of the 12 species examined display a more plastic feeding behaviour and this fact allows for low-cost dietary changes. Changes in feeding behaviour with food availability are a feature of several fish species (Gerking, 1994). The cost-benefit relationship (optimum foraging theory) during foraging can reach a threshold where a particular type of food chosen might have previously been refused. These changes, which are related to resource availability, are adaptive as they allow the individuals to survive in conditions that would otherwise be disadvantageous (Gerking, 1994).

Wallace Jr. (1981), concluded that food similarity is biologically significant when α (Schoener's index) is higher than 0.6. In the current study, for both winter and summer, regardless of zone or age group the overlap indices approach 1.00 i.e., near total overlap (Tables 5.4 to 5.9 pages - 219 - to - 222 -). Matthews (1998), based on a hypothetical overlap of the resource use as a function of habitat availability, suggested that at "moderate" levels of resource availability the species could diverge in their food niche by becoming specialists, thus decreasing the overlap. However, in extreme situations of "high" or "low" abundance of resources, it is possible to find high overlap degrees. When resource availability is high the species may make use of it opportunistically, becoming generalist. In this case, despite the high overlap degree, the species would not necessarily compete, as the resource is highly abundant. This appears to be the case between fish as foragers and macroinvertebrates as food sources in the Thames Estuary based on data presented in Appendix 5.

At the other extreme, when resource availability is low, the species may converge on an identical resource. In this case the overlap would also be high and would probably lead to competition. The species would tend to be generalist not because of the high number of items available but due to food shortage. Based on current evidence that food availability is higher in summer, it can be postulated that there is no competition and that fish species are more generalist in this period, so much so that diet overlap occurs in almost all cases in summer. However feeding mechanisms that could lead to specialisation or generalisation have not been defined in the current study. Furthermore, morphological and physiological specialisation can also influence fish feeding behaviour should also be considered.

Based on the stomach data gathered in the current study, it can be said that change in feeding strategy is caused by extrinsic factors (variation in availability of some foods during the year) and is an adaptive response. Fish in the upper and middle Thames Estuary are successful in foraging due to year-round food availability. When the preferred food of a species undergoes availability variation during the year, there are various consequences. Competition may arise when different individuals or species are limited by space or a given resource and one necessarily deprives the other. In winter, the switching of diet tendency observed by the majority of the fish species must be a way to minimise the competition process and it may indicate that food diversity has generally diminished. Even when competition is significant, its influence may be felt by only a small proportion of the species interacting within a community. Questions about the effects of competition on estuarine diversity may be studied through experiments or by testing appropriate neutral models, which await development and are beyond the scope of this study.

In interpreting the diet selectivity indices (section 5.3.7 pages - 195 - and Tables 5.11 to 5.15 pages - 223 - to - 229 -) in the two ecological zones, some questions were asked: The first question was whether a fish species can exhibit "selective" feeding strategies and "neutral" feeding strategies in an estuarine environment. If a fish species feeds selectively in one habitat and possesses a different diet downstream with different food-items selectivity values, is it still a selective forager or an opportunistic forager (adapted to different forage availability)? Or is it both? Selectivity data must be interpreted with caution. "Selective" and "opportunistic" are not necessarily opposing consumer characteristics: the 12 fish species studied in the Thames estuary have access to 3 food categories/groups ('Crustacean', 'Other', and 'Fish') and they consume them in proportion to their abundance in the summer season (non-selective). In winter, there is a reduction in availability of oligochaetes in many areas of the estuary, and favourable elements of the group 'Other' such as chironomids, terrestrial insects, gastropods etc, but micro and macro crustaceans, especially the gammarids become more abundant (see chapter 3). As a result in winter over 80% of fish diet was macro and micro-crustaceans, despite the fact that there still were significant numbers of fish, chironomids, oligochaete worms and gastropods. The selectivity indices indicate that these fish have become much more selective during the winter season towards crustaceans but is it correct to consider the predators as less opportunistic during the winter? The predators may have been ignoring some resources (oligochaetes worms, gastropods, fish etc), but from a food availability point of view they may be consuming more food for the same foraging effort by feeding predominantly on crustaceans. This implies that the 0+ and 1+ fish were demonstrating their opportunistic nature during the winter. These fish would have been less opportunistic if they did not take advantage of the abundant crustaceans. It is therefore difficult to place the "selective" and "opportunistic" labels on opposite ends of the continuum; they are more reliably treated as independent characteristics.

Furthermore, the concept of selective/opportunistic feeding has been developed for species which find their prey visually. So each time the fish sees a potential prey it has a choice whether to try to feed on it or not. However, most benthic fish e.g. flounder, mullet, gudgeon and goby do not feed predominantly by sight. In most cases the fish is just taking up substrate, processing it and keeping whatever it is able to keep, hence the high proportion of silt in the guts of these species. So the choice the fish can make is mainly where and when it starts to dig up substrates. It may be quite selective in this respect, e.g., it prefers certain substrates over other etc. On the other hand it may screen the environment and feed on the most profitable patches of food.

Revelations of the associations between fish and their diet were made by the fish-diet matrices obtained from analysing the gut samples. Cluster analysis of fish and their diet help to elucidate the structure of the foraging fish community in the upper and middle Thames Estuary (see section 5.3.9 page - 196 - and Figures 5.1 to 5.12; pages - 229 - to - 244 -). The cluster graphs have grouped fishes that have similar food habits; for example, regardless of differences in feeding localities and seasons, sea bass, smelt, perch and eels have closer similarity relationships in the cluster graphs in relation to their feeding strategies. These are piscivorous fishes in addition to being heavily crustaceavorous; they feed very little on worms and other benthos but they display the highest diets widths. Roach, dace, gudgeon also have closer diet similarity relationships, displaying selection for 'Other' food items and crustaceans but not being piscivorous. Likewise the cluster analysis reveals groups of food items that species with similar food habits will select.

This chapter on the diet of small fish in the upper and middle Thames Estuary has provided insights into the variety of food items consumed by different age groups of fish. It also demonstrates the seasonality and zonal changes in diets which are linked with food availability. It can be concluded at this stage that most fish fry and juvenile fish are dietary opportunists and are capable of capturing a wide variety of food items. Clearly the overlapping diet between species may lead to competition for food but as most fish examined, even in winter had obtained food, there was no evidence for food being in critical short supply. Nevertheless species and age related preferences are quite clear for the majority of species present and at some times of the year and in different habitats within the estuary these items may be locally in short supply. Most species eat a wide range of prey items, and most species show shifts in food types between 0+ and 1+. There is also variation in diet composition over an annual cycle, illustrating the opportunistic feeding behaviour of fish.

The variety of food types found in fish stomachs from two seasonal samples reflect changes in food preferences and availability as the fish grow (ontogenetic changes) and the opportunistic nature of most fish species. Yanez-Arancibia (1986) notes that the whole trophic structure in a locale does not comprise specific levels as fish eat food from a variety of sources. The use of diet widths and overlap indexes produced interesting results and were to be an indication of diet or resource use (Winemiller & Kelso-Winemiller, 1996). What can be done in future work is to calibrate the electivity index, and then compare the estimated food availability with actual assessment of food quantity in the environment. This would result in higher precision of estimates. Although invertebrate population estimations were available as part of this thesis they are not detailed enough to be used for accurate calibration of the electivity index. Other aspects of this study that need to be addressed in the future are the temporal and spatial resolution of the diet matrix. Increase in the number of individuals within a species for gut analysis will improve the diet matrix model and can then be used for computation of standard ecological parameters.

Chapter 6

GENERAL DISCUSSION

This study has provided much information on the interrelationship between the macroinvertebrate and fish fauna of the upper and middle Thames estuary and its associated tributaries, creeks and dock basins. This information was gained through the collection and analysis of biological datasets obtained from three separate studies: 1) the distribution and abundance of benthic macroinvertebrate species in the upper and mid Thames Estuary and its associated dock basins and creeks; 2) the composition and relative abundance of fish species in the upper and middle Thames Estuary and its associated tributaries and dock basins; 3) ontogenetic, spatial and temporal analysis of the gut contents of the 12 most common fish species in the upper and middle Thames Estuary.

Results from the invertebrate study concluded that the low salinity upper estuary sites produced the largest number of macroinvertebrate species/families per given number of individuals and middle estuary and creek sites produced the largest number of individuals but the lowest species diversity. The Royal dock basins had specialised benthic invertebrate groups, whilst the East India Dock basin had a benthic macroinvertebrate composition similar to that of the main river. The mudflats of the mid estuary creeks displayed very high abundances and dominances by oligochaete and polychaete worms during summer; and their central channels by freshwater species (mainly of upstream of the tributary origin). The study also indicated that habitats with similar physical and other environmental conditions yielded similar macroinvertebrate assemblages.

In the fish study a total of 26 species were captured in all the sites sampled; 10 species were common to all the sites. Twenty two species were recorded in the upper Estuary and 22 in the mid Estuary. Eighteen species were common to both the upper and middle Estuary. Eleven species were recorded in the Queen Victoria Dock Basin, 21 in the East India Dock Basin and 14 in the Dartford Creek. The most abundant family recorded through out the study was the Cyprinidae with 8 species occurring, mainly in the low salinity areas of the upper Estuary and the two arms of the Dartford Creek. In the brackish waters of the mid Estuary, East India and Queen Victoria Dock Basins a far greater contribution came from marine species, although all families recorded in the tidal Thames except Cottidae were present in the mid Estuary and the East India Dock Basin.

Finally the gut content studies concluded that benthic macroinvertebrates were the main diet for fish of all age classes and that 0+ year classes consumed a smaller range of food items than the 1+ year classes. 1+ year classes consumed a narrower range of food items in winter than in the summer. The more generalist feeders, comprising perch, eel, smelt, sea bass and three-spine stickleback consumed a greater range of food items. There were variations in food availability and species feeding selectivity (β). Diet overlap values between all species, as measured using Schoener's index (α), were very high regardless of ontogeny or seasonal changes or the spatial distribution of the individuals and ranged from 0.89-1.00. Species tendency to be more generalist (diet width, δ) was lowest during the post larval stage and during winter and was highest in the summer. Results of the macroinvertebrate study suggested that there was no shortage of potential food items in the winter as winter and summer macroinvertebrate mean densities revealed no significant differences in numbers. However, the differences between the mean species richness were significantly different, inferring differences in food composition between summer and winter seasons.

Two main types of brackish water environments were explored in the current study namely: 1) the main estuary i.e. the region through which the river Thames discharges to the North Sea and 2) the artificial impoundments or dock basins i.e. bodies of mid estuary water that are separated from the adjacent estuary by barriers of concrete walls but nevertheless derive their salt water from the brackish portion of the main river. In other parts of the country and elsewhere, brackish water may also occur in coastal lagoons and inland seas (e.g. the Baltic Sea) etc. In the current area of study the main estuary and the East India Dock exhibit dramatic tidal changes in water levels and therefore possess intertidal zones. However, in the Royal Dock basins, water levels do not fluctuate in the same fashion and have no intertidal zones.

As far back as 1922, (Redeke, 1922) and several authors (e.g. Aguesse, 1957; Bulger *et al* 1993; den Hartog, 1964) have attempted to classify brackish waters (particularly landlocked ones) largely on the basis of their salinity on one hand and their fauna on the other hand. None of the various classifications proposed have been entirely successful, however, not only because of major differences in the fauna of estuaries and largely landlocked lagoons and brackish ponds, but also because brackish waters cover such diversity of habitat types and within them each species has its own individual distribution pattern in relation to salinity. Nevertheless it remains true, as one might expect, that organisms of freshwater origin are a more significant component of the more dilute systems, and that essentially marine species are more characteristic of high salinity and of those with an open connection to the sea. Both the macroinvertebrate and fish datasets in the current study confirms the classic view of species assemblages in estuaries according to salinity. The salinity gradient between upstream sites Teddington and Hammersmith (Tinsley, 1998) and downstream sites (Hammersmith – Battersea) in the upper estuary contributed to the slight separation between the freshwater cyprinid dominated fish populations in the former, and estuarine fish dominated populations, especially flounder and goby, in the latter. The high abundance of estuarine smelt, sea bass, and stickleback in the mid estuary, and the East India Dock, the high abundance of smelt and the marine straggler sand smelt in the Queen Victoria Dock basin, and the abundance of smelt, herring, and sea bass in the Dartford Creek all contrast with the high abundance of roach, dace, bream, perch, gudgeon in the low salinity reaches of the upper estuary and the two low salinity Darent and Crayford Arms of Dartford Creek, a major tributary of the mid Thames estuary.

This species-habitat partitioning with respect to salinity was also observed with the invertebrate dataset. Macroinvertebrate species of freshwater biogeographic origin were more common in the upstream sites of Teddington and Hammersmith. *Asellus aquaticus, Helobdella stagnalis, Glossiphonia complanata Dreissena polymorpha, Erpobdella octoculata, Glossiphonia heteroclita, Mytilus edulis, Assiminaea grayana* and the oligochaete species *Brachiyura sowerbyi* were exclusively found in the low salinity upper reaches of the estuary and the upper estuarine Chelsea Creek. In the middle estuary, East India Basin, the Royal Dock basins and the creeks brackish water fauna of marine biogeographic origin dominated. These included crustaceans such as *Palaemonetes varians, Corophium anenarium, Corophium lacusta, Corophium volutator, Crangon crangon, Carcinus maenas, Balanus amphitrite, Balanus improvisus*, the polychaete worms *Nereis diversicolor, Nereis virens, Nephtys bombergi* and the oligochaete worms *Heterochaeta costata, Monopyleothorus rubroniveus,* and *Potamothrix hammoniensis* (see Table 3.2)

However, although salinity and co-varying factors are the diagnostic features of the estuary and its associated brackish water habitats, they are perhaps not those that entirely determine the nature of brackish habitats from the view points of many species of macroinvertebrates. The more characteristic species are markedly euryhaline and can survive anywhere within a range in the order 4 – 35 ppt (Andrews, 1984; Barnes, 1994). Importantly, the upper and mid Thames estuary and its associated tributaries, docks and creeks are quiet environments, sheltered from wind action and heavy waves by the surrounding land. Wherever it is quiet in the estuarine zone, fine sediments such as silt and clays tend to settle out of suspension in the water column, thus the mid estuary and its associated creeks are characterised by the presence of mudflats. Different macroinvertebrate species are adapted to the various substrates present throughout in the estuary and its associated docks and creeks. A brief description of the relationship between the substrates and the dominant species of the study areas follows.

The most abundant taxa sampled from the mud flats of the mid estuary were the oligochaete species. Oligochaetes were common in the upper and middle zones of the Thames Estuary, but they were often ignored by previous workers because they were thought to be extraordinarily difficult to identify. The extensive taxonomic work done since 1982 by Brinkhurst (1982), however, has enabled routine identification of most of the British oligochaetes from simple whole mounts. Some oligochaete worms closely resemble terrestrial earthworms while others can be much narrower or thread-like. Many oligochaete worms can tolerate low dissolved oxygen and may be found in large numbers in organically polluted habitats (Andrews, 1977 and 1984; Wood, 1982)

Four families in the orders Tubificida and Lumbriculida are common in the Thames Estuary: the Tubificidae, Naididae, Lumbriculidae, and Enchytraeidae. Enchytraeidae species were very difficult to identify and there were no definitive keys for their identification.

The tubificids are probably the best known of the freshwater oligochaetes. They are most commonly found in soft sediments rich in organic matter, and several species characteristically live in sites that receive organic pollution such as the creek mouths. Like all aquatic oligochaetes, tubificids respire cutaneously, but a unique feature of this family is that some species can tolerate anoxic conditions. Most tubificids are deposit feeders, subsisting on organic detritus and its associated microflora. The Naididae is an ecologically diverse family of worms common in both running and standing waters. Many naidids are sediment dwellers, like the tubificids, but other species are characteristically found among aquatic plants. In the Thames estuary, enchytraeids are common in marginal aquatic habitats such marshes, and interstitial waters along the margins. Because of taxonomic difficulties, very little work has been done on the ecology of enchytraeids in the UK.

Of the annelids in the Thames estuary, the oligochaetes display the greatest diversity and have the greatest indicator value. The two families, Naididae and Tubificidae form 80 to 100% of the annelid communities in the benthos of most sites at all trophic levels.

Oligochaete worms were diverse, and occurred in the full spectrum of fresh and brackish waters. As water bodies and courses become organically polluted and dissolved oxygen concentrations become reduced or are eliminated, an abundance of tubificid oligochaetes is commonly found concomitant with a precipitous reduction and exclusion of most other benthic animals. As long as some oxygen is periodically available, and toxic products of anaerobic sedimentary metabolism do not accumulate, the rich food supply and freedom from competing benthic animals and predators permit rapid growth and high population densities.

The classical "pollution indicators" are *Tubifex tubifex* and *Limnodrilus hoffmeisteri*. Both species are able to survive periods of anoxia, such as occurs in the Thames Estuary and its creeks during the periods of high organic pollution especially during the summer months. Most tubificids have erythrocruorin, a red blood pigment, which effectively extracts oxygen dissolved in the water. The densities of *Tubifes tubifex* and *Limnodrilus hoffmeisteri* in sewage lagoons may be so high that the bottom appears pink. The dominance of oligochaete species in the mid estuarine creeks during summer and their complete replacement by amphipod crustaceans during winter could indicate poorer water quality during summer and improved quality during winter at the creeks and main river.

Other substrates occur in the Royal Dock basins and attract the development of specialised organisms, e.g. the concrete walls of the dock basins. The most numerous organisms after oligochaete species were organisms belonging to the crustacean families Crangonidae, Gammaridae, Palaemonidae, Sphaeromatidae and Jaerinidae the reef forming annelids Sabellariidae and the bryozoan Victorellidae. Two very interesting organisms from the two families were *Sabellaria alveolata* and *Victorella pavida* respectively. *Sabellaria* reefs or crusts typically form on hard substrata such as bedrock, so their presence on the concrete dock walls is not surprising. However, they can also form on a variety of other substrates (Hiscock, 1991; Rees & Dare (1993; Larsonneur 1994; Warren & Sheldon, 1967; Schafer, 1972; Warren, 1973).

The habitat created by *Victorella pavida* and *Sabelaria alveolata* reefs in the dock basins, and the resulting increase in richness and diversity of the community, are among the most important reasons for which they could be identified in general terms as being of conservation interest. A variety of invertebrates is found within the accumulations of *Sabellaria alveolata* and *Victorella pavida*, with some larger crustaceans such as *Crangon sp*, *Gammarus spp*, *Sphaeroma sp*, and *Palaemonetes* sp inhabiting in between *Sabellaria* and *Victorella* dead tubes. These are no doubt fed upon by the fish present in the dock basins. The tubes themselves also were observed to support encrusting flora such as algae, particularly *Fucus vesiculosus* and green algae such as *Enteromorpha*, was also present.

The gravel and sandy substrates of the upper estuary is home for Gammaridae species although this family is present throughout the estuary and its associated tributaries, creeks and docks. At Teddington and Hammersmith, gammarids were present at the bottom of rocks, stones and dead wood. At the creek sites *Gammarus sp* were primarily sampled from the central channels consisting of sand and gravel and stones. At the dock basins *Gammarus* were present in the algae encrustations and dead *Sabellaria* reefs. Gammarids are sensitive to gross organic pollution and require water with substantial oxygen saturation. *Gammarus zaddachi* tend to be more abundant in winter and absent in warm polluted summer waters.

Recolonisation for this species was difficult after pollution was abated in the estuary (Huddart, 1971; Wheeler 1979; Sedgwick, 1978; Andrews, 1984).

Unequal distribution of fish species in most of the sampling sites was observed. This inequality in species distribution was as a result of differences in salinity tolerances by different species. Lorenz curves were an effective way of visually showing inequality of species distribution within and between sites or zones. The cumulative percentage of fish population was plotted against ranks of abundance of species (Figure 4.30) to produce the Lorenz Curve (Lorenz, 1905).

The Lorenz curves for Greenwich, Belvedere and the River Cray (Dartford Creek) were closer to the 45-degree line (Figure 4.30) depicting a more equal distribution of fish species at these sites. The Lorenz curves of Grays, Queen Victoria Dock, East India Dock, Battersea, Hammersmith and Teddington bend away from the 45-degree line of absolute equality, depicting a less equal distribution of fish.

Sites with concentration indices between 0.5 and 0.75 were regarded as having unequal species distributions whilst sites having concentration indices between 0.02 and 0.40 were considered to have relatively equitable species distribution. Two sites (Belvedere and Greenwich) exhibited low concentration indices (0.02 and 0.36 respectively) Sites that exhibited high concentration indices were Teddington (0.70), Hammersmith (0.67), Battersea (0.55), Grays (0.67), Queen Victoria Dock (0.75) and East India Dock (0.63). These sites were dominated by a few species. For Teddington the dominant species were roach and dace and for Hammersmith and Battersea the dominant species were dace, roach and the summer post larvae of flounder. Sites with low concentration indices included Greenwich and Belvedere (Table 4.20). At Teddington, Hammersmith and Battersea the apart from the seasonal high occurrence of post larvae flounder the most represented species were those of freshwater biogeographic origin. This distribution of the concentration index shows that species diversity is higher at the middle of the estuary and falls in the freshwater and towards the marine ends where marine species cannot tolerate the lowered salinity of the freshwater end and *vice versa*. At Queen Victoria Basin with a concentration index of 0.75, a single species sand smelt contributed 75% of the fish population had an extremely unequal species distribution. The water at the Queen Victoria Dock is brackish but does not undergo salinity fluctuations due to lack of or little tidal activity. The stable water system provides a stable environment for the proliferation of species that find the salinity level in basin favourable. A dense population of sand smelt occurs in this basin.

Greenwich and Belvedere are located in the zone of the estuary subject to strong salt and freshwater mixing. At these sites species of both freshwater and marine biogeographic origin were well represented. The fish fauna of the brackish-water stretches of Greenwich, Belvedere and Dartford Creek are therefore mainly impoverished versions of those marine and freshwater fauna that inhabit the middle reaches of the estuary. Specifically, they comprise those essentially marine species (flounder, sea bass, smelt, three-spined stickleback, dab, plaice, mullet, sand goby, herring and sprat) that can withstand low and fluctuating salinities. They also comprise those freshwater species (roach, dace, perch, gudgeon, bream etc) that typically occur and breed in freshwater. Because fauna of both marine and freshwater biogeography are well represented at these sites the species diversity is high and the concentration indices are low.

Grays is an area of brackish zone water tending towards full seawater. Species recorded include marine species (dab, plaice, sea bass, sand goby etc) and included no fresh water species. The concentration index here was high as expected.

The benthic macroinvertebrate diversity partly conformed to the classic view of estuaries (Remane and Schlieper 1971). Species diversity was higher in the freshwater end of the estuary and fell at lower levels at the mid estuarine sites. A more marine macroinvertebrate fauna was found in the mid zone of the estuary dominated by oligochaete worms. It is also in this zone that the major Sewage Treatment Works (STWs) of Becton and Crossness discharge. Sampling macroinvertebrates from within this zone indicated there were a number of sites which show a high degree of stress. At the Dartford, Barking, Deptford and Bow Creeks as well as Belvedere and Greenwich sites the benthic invertebrate fauna was indicative of sites of relatively stable mudflats, significantly influenced by organic enrichment. Moreover, STWs are also located close to all the creek sites. Oligochaete worms form a large part of the macrobenthic community and were present at high densities.

The current study did not extend sampling to the outer estuarine zone where benthic species diversity was also expected to be higher than that of the mid estuarine sites (Attrill, 1998). The Shannon-Weaver index (Shannon and Weaver, 1949) was used to show macroinvertebrate species richness and evenness within each habitat and sites sampled. The higher the Shannon-Weaver indices the more diverse and evenly distributed the species in the samples. The low salinity sites of the upper estuary had higher Shannon-Weaver indices. The creek and dock basin sites (except the Deptford Creek) had lower Shannon-Weaver indices (Table 3.10 and Figure 3.3). The existence of lower species diversity in the creeks and other mid estuarine sites was a function of salinity levels which also have a positive correlation with the existence of mud flats. Mudflat habitats have a high capacity for the development and growth of oligochaete and polychaete worms but low capacity for the existence of gravel, sandy or stony substrates dwelling organisms.

Marked seasonal changes in structure were detected in all estuarine fish and macroinvertebrate communities. Taking the fish situation first, the abundance of species and individuals was generally highest in late spring and summer due to the influx of juveniles of both resident and transient species following their breeding seasons. This influx of juveniles also had a profound effect on the age structure, and because not all species recruited at the same time, on the species composition. The subsequent decrease in numbers and species may be the results of a variety of factors. Mortality caused by low temperatures was not observed as no dead fish were caught during the winter. The most commonly cited cause for the low winter numbers in the Thames estuary is migration (Wheeler, 1979; Araujo, 1992; Araujo *et al*, 1998 and 1999; Colclough *et al*, 1999, 2000 and Colclough, (2001). There was a dynamic pattern of migration in and out of the upper and middle estuary by those species which utilize the estuary as nursery grounds. Other species, such as flounder utilize the upper estuary mostly in summer and migrate back to the lower estuary as the temperatures dip. Most species are present throughout the year in the upper and mid estuary but only their 1+ are mostly present in winter. Hence, the seasonal pattern of abundance of fish species in the upper and mid estuary may be more a question of life-history strategy, mainly related to spawning period, than tolerance of adverse environmental conditions. The peak abundances of the 12 most abundant species in the upper and mid estuary were as follows: roach June-November; dace February-March; flounder May-July; gudgeon July-September; perch July –

September; bream October-December; goby September-December; smelt August-September; sea bass July-September plaice and dab August-March and 3-spined stickleback May-October. The peak abundance of bream, place and dab was recorded in winter, when 1+ individuals were captured in the mid estuary (see Figure 4.16).

Use of creeks and dock basins as winter refuges for juvenile fish was not substantiated. There was no evidence that creeks and docks were used as winter refuges by juvenile fish. It was the initial belief that creeks and docks might offer a potential explanation for the apparent disappearance from the main estuary.

The impact of winter on the estuarine organisms was more marked for macroinvertebrates than fish, especially in terms of species richness. In winter many species apparently disappeared including many of the oligochaete species. Amphipod crustaceans were more abundant in winter, but populations of decapod crustaceans fell. The summer-winter species ratios for the different environments were as follows: main river (62:54); East India Dock basin (21:20); Royal Docks (18:15) and the creeks (30:18). Generally there was a loss of species in all environments in winter. It appeared also that macroinvertebrate organisms in the creek environments were more sensitive to winter conditions than those in the main river or the dock basins which may reflect their extreme tidal fluctuations and the type of macroinvertebrate organisms that inhabit them (see Table 3.3). Oligochaete species can easily be washed away by fast flowing water during winter storms. In addition water quality may be far better in winter, with higher oxygen saturation and lower organic matter.

A notable feature of the estuarine fish fauna is that it comprises a limited array of feeding types and that many of the species are extremely generalists in their diets. The most significant aspect of the Thames estuary, with its open connection to the sea, is its use as a fish nursery ground, particularly during the summer months. Flounder has a life cycle in which the juveniles inhabit and feed in brackish waters and 1+ grey mullet and sea bass feed in the mid and lower upper estuary too. Juvenile true estuarine, estuarine dependent and marine visitors feed unselectively on invertebrates and young fish while 1+ grey mullet and flounders also take larger mouthfuls of detritus and mud.

Selectivity indices for all species were very small in both summer and winter (Tables 5.10 – 5.15). Diet overlap indices ranged from 89% to 100% indicating the lack of specialization in feeding strategy (Tables 5.4 – 5.9). Diet widths ranged from 4 items in 0+ mullet to 24 items in 1+ eel (Table 5.3)

Conclusion and Recommendations

The ways in which the fish and macrobenthofauna of the upper and mid Thames Estuary and its associated tributaries, creeks and dock basins, are ecologically connected and affect one another have been broadly established and described in Chapters 3, 4 and 5 and discussed in Chapter 6. A summary of these broad establishments are outlined below:

1. In Chapter 3 it has been established that benthic macroinvertebrates comprise a broad assemblage of diverse forms that are related only by their distribution in space, rather than by phylogeny or exclusive functional attributes. Nevertheless, the fact they spend part of their lives in intimate association with the bottom results in certain unifying consequences, both for the organisms and for the estuary. Species composition transition from one zone of the estuary to the next has been established to be gradual with species changes within families then whole families become less important until they are replaced by another species. This gradual transition in species composition is dictated by previously established salinity gradients (Environment Agency, 1997; Kinniburgh, 1998). Changes between main river and representative creeks and docks are abrupt.
2. This study has confirmed previous observations that freshwater habitats (low salinity zones) of the Thames Estuary foster freshwater species of upstream biogeographic origin. In addition it has been confirmed that these freshwater habitats have higher macroinvertebrate species richness than their counterpart brackish water habitats (Andrews, 1977; Andrews 1984; Andrews *et al.* 1992; Attrill 1998; Attrill and Power, 1999). The reasons given by previous workers in the Thames Estuary for this situation is that freshwater habitats provide stable and less hostile environmental conditions all day and all year round apart from the inevitable effects of seasonal changes and stochastic weather conditions.
3. Generally in the mid estuary, the creeks and East India Dock Basin, which are characterised by major tidally induced salinity variations, macroinvertebrate

populations occur at high population densities but low species richness. Obligate freshwater or marine species which cannot tolerate the salinity variations are eliminated. Those that can tolerate the fluctuations in environmental conditions utilise and take advantage of the organic nutrient rich environment and thrive in very high numbers, especially the oligochaete and polychaete worms in the mudflats. It is confirmed that these habitats provide the physical features favourable for soft bodied burrowers. The habitats also harbour other estuarine dependent species and these comprise *Palaemonetes sp*, *Crangon sp*, and mycids as well as a very limited number of salinity tolerant freshwater species comprising *Gammarus sp* and *Asellus sp*.

4. It has also been established that the creek central channels, which are characterised by the presence of freshwater flow at low tide, hold a wide range of freshwater benthic invertebrate species. These freshwater central channels are partly responsible for bringing into the brackish water zone freshwater benthic invertebrate species that would otherwise not be normally found here.
5. The Royal Dock Basins being completely impounded water systems have very diversified and more evenly distributed macroinvertebrate species assemblages. Their physical features include the presence of algae encrusted walls which act as substrates for macroinvertebrates. However, although they are not tidal, the Royal Docks are brackish in nature and therefore exhibit a presence of brackish water crustaceans and other organisms.
6. The ways in which fishes of the different ecological zones are connected have been broadly established in Chapter 4. True estuarine species are few because only a few species can permanently survive the hostile conditions or experience of daily changing environmental conditions especially the fluctuating salinity of the mid estuary. Instead transient species (species which visit the estuarine zone for the purpose of feeding and breeding) are dominant (Wheeler, 1969b; Wheeler, 1979; Tinsley, 1998; Colclough, 1992 and 1996; Araujo *et al.* Colclough *et al.* 1999 and 2000; Colclough, 2001). The connections between the fish species and between the fish and their environment are partly phylogenetic. On one hand it has been established that fishes of the upper estuary (low salinity zone) mainly belong to the family Cyprinidae. This family is seasonally mixed with migratory species comprising spring and summer marine migrants and true estuarine species. On the other hand fishes in

the mid estuary are not strictly connected phylogenetically. They are made up of a mixture of permanent resident species and immigrant species of upstream and downstream origins belonging to a wide range of taxonomic families.

7. Broadly the connections and effects on each other of the estuarine ichthyofauna have been established to depend on their lifestyles, namely the use of the estuary for breeding, feeding and distribution pattern of the species in space and time. There are the freshwater species which seasonally penetrate into low salinities for feeding but not for breeding purposes. Many may be displaced into the mid estuary by spates. These comprise roach, dace, perch and chub. The study has re-established that marine species penetrate the mid estuary and creeks during high tide as opportunistic feeders. These comprise mullet, herring and sprat. The study has confirmed that migratory species are marine species which use the low salinity areas of the estuary as Primary Nursery Areas (PNAs). These are the dominant ichthyofauna of the main estuary, East India Dock Basin, and Dartford Creek. They include flounder and smelt. This study has therefore re-established the Thames Estuary as a Primary Nursery Area for migratory fish. The marine-estuarine dependent species include dab, place, mullet, herring and sprat. These are actually marine species which use the mid estuary for feeding.
8. Estuarine fish spend most or all their lives in the euryhaline conditions. "True" estuarine fish which spend all their lives in the brackish water of the main river, dock basins and the creeks include sticklebacks, common goby and sand smelt. Finally, eels do not fit any of the forgoing categories and being largely opportunistic may be found in any part of the estuary at any time and at any stage in the continental phase of their life cycle.
9. It has been established that Queen Victoria Dock has very few migratory species even during spring and summer (the spawning period for most migrant fish in the estuary), but true estuarine species are very abundant. The reason for this, as established in Chapter 2 and 3 is due to the fact that the water is enclosed and the ingress and egress of migratory species is an opportunistic event occurring only when the lock gates are opened. Those species which can breed and mature in the basins without any need to migrate to the sea dominate e.g. sand smelt and the smelt. Those species which need to migrate to the sea to mature do not do very well and their

populations are very much limited to occasional species e.g. flounder. It has therefore been established that impoundments "sieve" organisms to retain only those species that can survive the resulting conditions of isolation rather than the creation of "island effects" as the *a prior* belief was. The Queen Elizabeth Dock Basin is a refuge for the organic pollution sensitive species sand smelt and smelt. However, their dominance may change with time. They may become osmotically stressed and then replaced by species that tolerate lower salinities due to the continued dilution of the artificial lakes by rainwater and the lack of tidal influence.

10. Many different macroinvertebrate taxa appear in fish stomachs and there is considerable spatial and temporal variation in food eaten even for the same species. The complexity of food sources found in fish stomachs appear to reflect changes in food availability and changes in preferences as fish develop from 0+ to 1+ and >1+ and the opportunistic nature of most of the fish species.
11. What links the benthic macroinvertebrate and the fish fauna in Zones 1 and 2 of the estuary is that benthic macroinvertebrates are the main food source for a majority of fish and that fish depend on macroinvertebrates during the juvenile stages of their life history. However, the carnivorous species progressively shift to a piscivorous diet as they get larger. Macroinvertebrates in the estuary contribute a large part of the diet of the freshwater, migratory, marine-estuarine dependents, the marine and the true estuarine species. Crustacea, both pelagic and benthic are the prime source for fish in the estuary although other types of invertebrates including insect larvae are also taken.
12. It was not possible to investigate the fish fauna of the Royal Albert and King George V Dock due to lack of suitable foreshores to lay the fry net. An appropriate sampling method is required to facilitate the description of the fish assemblages in these habitats. In addition, only a single site was sampled in the Royal Victoria Dock Basin, again due to the absence of suitable foreshores to lay the net in the rest of the basin. This study would have benefited from a multi-fishing gear approach comprising a combination of net sizes and depths to be able to thoroughly account for different sizes and ages of fish. The study would have also benefited from measurements of physicochemical data to enable the ordination of species with environmental factors or conditions for the different habitats. Resource constraints

were a major impediment to these activities. However, despite these limitations, the majority of the objectives have been achieved and the interrelationships between fish and macrobenthofauna of the upper and mid Thames Estuary and its associated creeks, tributaries and dock basins have been broadly established.

Recommendations

1. The continuation of baseline monitoring in the dock basins, creeks and main river catchment is recommended, in order to understand the long-term changes in the ecological communities. Furthermore, the sources of pollution, as well as their effects to the water quality were not evaluated in this study. Therefore ongoing monitoring of water quality in the catchment, particularly in relation to known sources of pollution, is needed to provide a useful resource for future studies in the catchment. Boey (1997) recommends that a water quality-sampling program should be designed to meet requirements of water quality guidelines. Along with monitoring of physical-chemical parameters, Boey (1997) suggests that biomonitoring can complement such a program. We suggest a similar program as the Boey, but more extensive sampling of the streams and creeks around the catchment may also be of interest. In addition, this study allows evaluation of any future management plans that are undertaken within the Thames estuary catchment, using the benthic macroinvertebrate data to monitor changes over time. For example, an increase in macroinvertebrate diversity may be an indication of improvements in water quality within the estuary in line with the Environment Agency Species Diversity National Action Plan (2000).
2. Saltmarsh restorations are recommended in order to achieve the aims of the Environment Agency Habitat Action Plan for the Tidal Thames (Environment Agency, 2000). The underlying assumption is that restoration of Saltmarsh habitat is beneficial to the Thames Estuary fish populations and macroinvertebrates since such habitats are critical to early fish life history. That is, such habitat should qualify as essential fish habitat. However, these assumptions have not been fully tested.
3. The restoration of the East India Dock Basin has proved to be a successful scientific forethought. This basin has been shown to have the highest species richness for both fish and benthic macroinvertebrate species. The probable short-tem and long-term consequences of such restoration activities on keystone estuarine species, namely

sand smelt and smelt, in the Queen Victoria Basin remain to be determined. Within the Royal Dock Basins, apart from the addition of gravel substrate in the West end of the Queen Victoria for water sports purposes, no restoration action (or rather transformation action) has been undertaken. The Queen Victoria Dock Basin appears to serve as a sanctuary for sand smelt and smelt. Before impoundments are opened or otherwise modified, as part of outlined restorations, the Environment Agency needs information on the probable effects of such action.

4. The Environment Agency also needs scientifically-based information on which habitats should be defined as essential fish habitat as a rationale for management activities. Sand smelt, smelt and sea bass are prime species in the Queen Victoria Dock Basin and throughout the mid estuary though their densities vary. Smelt, sea bass and sand smelt are known to be particularly sensitive to changes in water quality and other physical parameters which may accompany restoration actions. Adult fish spawn in deep water immediately adjacent to shallow flats and vegetated shoreline. In most estuaries, post larvae and early juveniles utilise these shallow marsh habitats as nurseries. It may be hypothesised that restoration actions should increase the extent of nursery habitat available to early life history stages of estuarine fish. However, adverse effects are also possible. Short term effects from restoration engineering may include the release and redistribution of muddy and/or anoxic sediments, hypoxic water and plumes of fresh or hyper-hyaline water detrimental to local fish populations. Long term effects may include potential degradation or elimination of spawning sites for smelt and sand smelt populations due to increased or reduced salinities, altered vegetation and altered flow patterns over near shore spawning and larval nursery areas in the estuary. Thus management decisions and resultant actions aimed at restoring and enhancing overall foreshore integrity, while maintaining key resident estuarine fish populations, will require the fundamental knowledge to be developed in a proposed research.

5. With regards to the fish diet metrics, their accuracy can be improved. What can be done in future work is to calibrate the electivity index, and then compare the estimated food availability with actual assessment of food quantity in the environment. This would result in higher precision of estimates. Although invertebrate population estimations were available as part of this thesis they are not

vigorous enough to be used for accurate calibration of the electivity index. Other aspects of this study that need to be addressed in the future are the temporal and spatial resolution of the diet matrix. Increase in the number of individuals within species for gut analysis will improve the diet matrix model and can then be used for computation of standard ecological parameters for the greater estuary.

REFERENCES

Abele, L.G. and Walters, K 1979. Marine Benthic diversity. A critique and alternative explanation. *Journal of Biogeography* **6**, pg. 115-126

Aguesse P. 1957. La classification des eaux poikilohalines, sa difficulte en Camargue, nouvelle tentative de classification. *Vie et Milieu.* **8**, pg. 341-363

Alberet, J.J. 1994. Les Poissons, Biologie et pseuplement. In: Durand, J. R., Guiral, D. and Zabi, S. G. F. (eds). *Environement et resources aquatique de Code-d'Ivoire. Tome 11 – Les mileux lagunaires.* Paris Orstom pg. 239 – 279.

Aldenderfer, M.S., and Blashenfield, R.K. 1984. Cluster analysis. Newbury Park, California, Sage Publications.

Allan, J.D. 1975. The distributional ecology and diversity of benthic insects in Cement Creek, Colorado. *Ecology* **56**, pg.1040-1053

Allan, J.D. 1995. Stream Ecology. Chapman and Hall. London UK

Andrews, M.J. 1977. Observations on the fauna of the metropolitan River Thames during the Drought in 1976. *London Nature* **56**, pg.44-56

Andrews, M.J. 1984. Effects of Pollutants at Ecosystem Level in the Thames Estuary. :*Pollution and Recovery.* Edited by Sheehan P. J. *et al.* John Wiley & Sons

Andrews, M.J., Aston, K.F.A., Richard, D.G. and Steel J.E.C. 1992. Macroinvertebrate Fauna of the Thames Estuary. *Nature* **61**, pg. 30-62

Andrews, M.J. and Richards, D.G. 1980. Rehabilitation of the Inner Thames Estuary. *Marine Pollution Bulletin* **11**, pg. 327-332

Araujo, F.G. 1992. Temporal and Spatial Changes in the Fish Community Structure in The Upper and Middle Thames Estuary. PhD Thesis University of London

Araujo, F.G., Bailey, R.G. & Williams, W. P. 1998. Seasonal and between-year variations of fish populations in the middle Thames estuary: 1980-1989. Fisheries Management and Ecology **5**, pg. 1-21

Araujo, F.G., Bailey, R.G. & Williams, W.P. 1999. Spatial and temporal variations in fish populations in the upper Thames estuary. Journal of Fish Biology **55** (4), pg. 836-853

Ascroft, R.L. 1900. Notes on the white fluke or flounder. *Proc. Trans. Liverpool Biol. Soc.* **14**, pg. 174-177

Ashford, J.R., White, M.G. 1993. June Cross-sectional structure and validation of the timing of annulus formation in otoliths of the Antarctic fish *Notothenia coriiceps* Richardson (Nototheniidae). *Cybium*, **17**(2), pg. 153-163;

Attrill, M.J., Rundle, S.D. and Thomas, R.M. 1996. The influence of drought induced low freshwater flow on an upper-estuarine macroinvertebrate community. *Water Research* **30**, pg. 261-268

Attrill, M.J. 1998. The Benthic Macroinvertebrate communities of the Thames Estuary: In A Rehabilitated Estuarine Ecosystem; The environment and ecology of the Thames Estuary (Ed. Attrill, M. J.) Kluwer Academic Publishers pg. 85-112

Attrill, M.J., Power, M. and Thomas, R.M. 1999. Modelling estuarine Crustacea population fluctuations in response to physico-chemical trends. *Marine Ecology-Progress Series* **178**, pg. 89-99

Attrill, M.J. and Power, M. 2000. Effect on invertebrate populations of drought induced changes in estuarine water quality. *Marine Ecology Progress Series* **203**, pg. 133-143

Attrill, M.J. 2002. A testable linear model for diversity trends in estuaries. *Journal of Animal Ecology* **71**, pg. 262-269

Bagenal, T.B. and F.W. Tesch. 1978. Age and growth. Chapter 5. P. 101-136. In: T. Bagenal [ed]. Methods for Assessment of Fish Production in Fresh Waters. Blackwell Scientific Pub. London.

Baker, J.A, Killgore, K.J. and Kasul R.L. 1991. Aquatic habitats and fish communities in the lower Mississippi River. *Rev. Aquat. Sci.* 3(3), p13-56

Baran, E. 2000. Biodiversity of Estuarine Fish Faunas of West Africa. *ICLARM Quarterly* **23**(4), pg. 1-9

Barbour, M.T. and J. Gerritsen. 1996. Subsampling of benthic samples: defense of the fixed-count method. *Journal of the North American Benthological Society* **15**, pg. 386-391.

Barbour, M.T., Gerritsen, J., Snyder, B.D. and Stribling, J.B. 1999. Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers: Periphyton, Benthic Macroinvertebrates, and Fish. Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Barbour, M.T. and Stribling, J.B. 1991. Use of Habitat Assessment in Evaluating the Biological Integrity of Stream Communities. In *Biological Criteria: Research and Regulation. Environmental Protection Agency* 44-5-91-005, Office of Water. pg. 24-38

Barnes, R.S.K. 1994. The Brackish-Water Fauna of the North-western Europe *Cambridge University Press.*

Barrera-oro, E.R. 1989. August Age determination of *Notothenia gibberifrons* from the South Shetland Islands, Antarctic Peninsula. *Subarea* 48(1), pg. 143-160,

Barrera-oro, E.R., 1990. July Age determination in Notothenia gibberifrons from the South Shetland Is., subarea of the Antarctic Peninsula. (Subarea 48.1). Buenos Aires. Instituto Antarctico Argentino. Contribucion **373**, pg. 19.

Beaumont, W.R.C. and Mann, R.H.K 1984. The age, growth and diet of the freshwater population of the flounder, Platichthys flesus in Southern *England. Journal of Fishery Biology* 25, pg. 607-616

Benke, A.C., Van Andel T.C., Gillespie, D.M. and Parrish F.K. 1984. Invertebrates productivity in a subtropical backwater river: The importance of habitat and life history. *Ecological Monograph* 54, pg. 25-63

Benthic Ecology Research Group 1997. Tidal Thames Foreshore Macroinvertebrate Survey Technical Report. Department of Biological Sciences, University of Plymouth, Drake Circus, Plymouth, Devon PL4 8DE

Berg, R., 1990. The growth of eels: A critical assessment of data from open waters. Int. Rev.Gesamt. *Hydrobiology* 75, pg. 755-62.

Blaber, S.J.M. and Blaber, S.T. 1980. Factors affecting the distribution of juvenile estuarine and inshore fish. *Journal of Fishery Biology* **17**, pg. 143-162

Boesch, D.F., R.J. Diaz and R.W. Virnstein. 1976. Effects of tropical storm Agnes on soft-bottom macrobenthic communities of the James and York River estuaries and the lower Chesapeake Bay. *Chesapeake Science* **17**, pg. 246-259.

Boey, A. 1997. Manly Dam Catchment water Quality studies: Report for the preparation Report for the preparation of a plan of management for Manly Warringah War Memorial Park. Department of Land and Water Conservation, NSW

Bowen, S. 1983. Quantitative description of the diet. P325-336 *in* Nielson, L. A. and Johnson, D. L. (Eds.) Fisheries techniques. American Fishery Society, Bethsda Maryland

Bowman, M.F. and Bailey, R.C. 1998. Does taxonomic resolution affect the multivariate description of the structure of freshwater benthic macroinvertebrate communities. *Canadian Journal of Fisheries and Aquatic Science* 54(8), pg. 1802-1807.

Brinkhurst, R.O., 1982. British and other marine and estuarine oligochaetes. Synopses of the British Fauna (New Series) (ed. D.M. Kermack & R.S.K. Barnes), The Linnean Society of London. Cambridge University Press, [Synopses of the British Fauna, No. 21].

Britain, J.E and Eikeland 1987. Invertebrate drift, a review. *Hydrobiologia* **166**, pg. 77-93

Bros, W.E. and Cowell B.C. 1987. A technique for optimizing sample size (replication). *Journal of Experimental Marine Biology and Ecology* **114**, pg. 63-71.

Budd, G.C., 2003. *Limnodrilus hoffmeisteri.* An oligochaete. *Marine Life Information Network: Biology and Sensitivity Key Information Sub-programme* [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 29/11/2004]

Bulger, A.J., Haden, B.P., Monaco, M.E., Nelson, D.M., and McCormick-Ray, M. G. 1993. Biologically-based estuarine salinity zones derived from a multivariate analysis. *Estuaries* **16**, pg. 311-322

Campana, S.E., 2001. Accuracy, precision and quality control in age determination, including a review of the use and abuse of age validation methods. *Journal of Fish Biology* **59**, pg. 197- 242.

Chen, C.Y. 1994. Aspects of the ecology of flounder, Platichthys flesus in the Upper and Middle Thames Tideway. A PhD thesis. University of London

Chisnall, B.L. and Kalish J.M. 1993. Age validation and movement of freshwater eels (*Anguilla dieffenbachii* and *A.. australis*) in a New Zealand pastoral stream. New Zealand. *Journal of Marine and Freshwater Resources.* **27**, pg. 333-338.

Chojnacki, J., Palczewski, P. 1981, November Age and growth rate of *Pseudochaenichthys georgianus* (family Chaenichthyidae) of the South Georgia region. *Polish polar research*, **2(3/4)**, pg. 145-157

Cochran, W.G. 1977. Sampling techniques. Third edition.John Wiley, New York, New York, USA.

Cohen, J.E. , Briand, F. and Newman, C.M. 1990. Community Food Webs: Data and Theory (Springer, Berlin).

Cohen, J.F., Jonsson, T., Capenter, S.R. 2003. Ecological community description using the food web, species abundance and body size. The Rockefeller University and Columbia University, Box 20, 1230 York Avenue, New York, NY 10021; and Center for Limnology, 680 North Park Street, University of Wisconsin, Madison, WI 53706

Colclough, S.R. 1992. Tidal Thames Fisheries Survey. First- Quarter May-July 1992. NRA (Now EA) Publication

Colclough, S.R., Dutton, C., Cousins, T. and Martin 1998. A fish population survey of the tidal Thames 1993. Environment Agency UK

Colclough, S.R., Dutton C., Cousins T and Martin 1999. A fish population survey of the Tidal Thames pg. 1994-1996

Colclough, S.R., Dutton C., Cousins T and Martin 2000. A fish population survey of the Tidal Thames 1997-1998. Environment Agency UK

Colclough, S.R. 2001. Fish Population of the Tidal Thames: A Draft Summary of Data Held by the Environment Agency as of March 2001. Unpublished

Colclough, S.R., Gray, G., Bark, A. and Knights, B. 2002. Fish and fisheries of the tidal Thames: management of the modern resource, research aims and future pressures *Journal of Fish Biology* **61** (supplement 1), pg. 64-73; Phone: 0207679 5299;

Courtemanch, D.L. 1996. Commentary on the subsampling procedures used for rapid bioassessments. *Journal of the North American Benthological Society* **15**, pg. 381-385.

Culp, J. M., Boyd, I. and Glozier, N. E. 1988. An improved method for improving gut contens from small, live fishes by anal and stomach flushing. *Copeia* **1988**, pg. 1079-1082

Cummins, K.W. 1974. Structure and function of stream ecosystem. *BioScience* **24**, pg. 631-641

Darnell, R.M., 1961. Trophic Spectrum of an Estuarine Community, based on Studies of Lake Pontchartrain, Louisiana. *Ecology* **42(3)**, pg. 553-568

Darnell, R.M. 1967. The organic detritus problem. In Lauf, G. (Ed.) Estuaries. *American Association for the Advancement of Science*, Publication **83**, pg. 374-375

Davidson, N.C. 1991. The conservation of British North Sea estuaries. *Hydrobiologia* **195**, pg. 145-162

Day, J.W. Jr., Hall, C.A.S., Kemp, W.M. and Yanes-Arancibia 1989. Estuarine Ecology. Wiley. New York

den Hartog, C. 1964. Typologie des Brackwassers. *Helgolander Wissenschaftliche Meeresuntersuchungen*, **10**, pg. 377-390

Digby, P.G.N. and Kempton, R.A. 1987. Multivariate analysis of ecological communities. Population and community biology series. Chapman and Hall. London, pg. 206

Dines, R.A. and Murray-Bligh, J.A.D. 2000: Quality assurance and RIVPACS. In: Assessing the biological quality of fresh waters: RIVPACS and other techniques. Wright, J. F.; Sutcliffe, D. W.; Furse, M. T. eds. *Freshwater Biological Association, Ambleside, UK*. pg. 71-78.

Edgar, G. and Shaw, C. 1998. The production and trophic ecology of shallow water fish assemblages in Southern Australia. 11. Diets of fishes and trophic relationships between fishes and benthos at Weatsern Port, Victoria. *Journal of Experimental Marine Biology and Ecology* **194**, pg. 83-106

Environment Agency 1997. Water Quality of the Tidal Thames. *Her Majesty's Stationary Office (HMSO)* .London

Environment Agency 2000. Local environment agency plan: The Thames Estuary, environmental overview. Environment Agency. London

Everitt, B.S. 1974. Cluster analysis (2nd end.) Heinemann Educational Books, London pg. 210

Foster-Smith, R.L., Sotheran, I. & Walton, R. 1997. Broadscale mapping of habitats and biota of the sub-littoral seabed of the Wash. Final report of the 1996 broadscale mapping project survey. A report prepared for English Nature and the Eastern Joint Sea Fisheries Committee.

Fowler, J., Cohen, L. and Javis P. 2003. Practical Statistics for Field Biology. Wiley

Fridrikson, A. 1934. On the calculation of age distribution within a stock of cod means of relatively few age determinations as a key to measurements on a large scale. *Rapp. P. V. Reun. Cons. Int. Explor. Mer* 86, pg. 114.

Gainey, L.F. and Greenberg, M.J. 1977. Physiological basis of the species species abundance-salinity relationship in molluscs. *Marine Biology* **40**, pg. 41-49

Gauch, H.H. Jr. 1982. Multivariate Analysis in Community ecology. Cambridge University Press

Gerking, S.D., 1994, Feeding ecology of fish. Academic Press.

Gibbs, J. and W. Martin. 1962. Urbanization, Technology, and the Division of Labor. *American Sociology Review*, **27**, pg. 667-677.

Goodyear, C.P. 1997. Fish age determined from length: an evaluation of three methods using simulated red snapper data. *Fish. Bull.* 95: pg. 39.46.

Haines, E. 1976a. Relation between the stable carbon isotope composition of Fiddler crabs, plants and Soils in a salt Marsh. *Limno. Oceanogr.* **21**, pg. 880-883

Haines, E., Montague, C. 1979. Food sources of Estuarine Invertebrates Analysed Using $^{13}C/^{12}C$ ratios. *Ecology* **60**, pg.48-56

Hair, J.F. 1992. Multivariate data analysis (3rd ed.). New York: Macmillan.

Hammond, R. and McCullagh, P. S. 1978. Quantitative techniques, in Geography: An introduction. Oxford University Press. Oxford

Hamrin, S.F., E. Arneri, P. Doering-Arjes, H. Mosegaard, A. Patwardhan, A. Sasov, M. Schatz, D. van Dyck, H. Wickstrom and M. van Heel M., 1999. A new method for three-dimensional otolith analysis. *Journal of Fish Biology.* **54**, pg. 223-225.

Hartley, P.H.T. 1940a. The Saltach tuck-net fishery and the ecology of some estuarine fishes. *Journal of Marine Biology Association.* UK **24**, pg. 1-68

Hauer, F. R. and Lamberti 1996. Methods in Stream Ecology. Academic Press

Hayes, B. 1993. A statistical method for evaluating differences between age-length keys with application to Georges Bank haddock, *Melanogrammus aegle.nus. Fish. Bull.* **91**, pg. 550-557.

Hess, A.D. 1941. New limnological sampling equipment. *Limnological Society of America Special Publication* **6,** pg. 1-5

Hill, A.E. 1991. Vertical Migrations in Tidal Currents. *Mar. Eco. Prog. Ser.* **75** pg. 39-40

Hiscock, K. 1991. Benthic Marine Ecosystems in Great Britain: A Review of Current Knowledge. Introduction and Atlantic-European Perspective. Nature Conservancy Council, CSD Report, No. 1170. Marine *Nature Conservation Review Report* No. MNCR/OR/006.

H.M.S.O. 1964. Effect of polluting discharges on the tidal Thames. Water Pollution Research Laboratory. Technical Paper II, London

Holmgren, K. and H. Wickström, 1988. Sättålens kvalitet 1987: en studie över kön, storlek, alder och skador (English summary: The quality of Swedish yellow eels used for stocking in 1987 – a study of sex, size, age and wounds) Information från Sötvattenslaboratoriet, *Drottningholm* 8, pg. 38.

Horn, M.H. and Neighbors, M.A. 1984. Protein and Nitrogen Assimilation as a Factor in Predicting the Seasonal Macro-algal Diet of the Monkeyface Prickleback. *Trans. Ame. Fish Society.* **113,** pg. 388-396

Horn, M.H. and Gibson, R.N. 1988. Intertidal fishes. *Scientific America* 258, pg. 64-70

Huddart, R. 1971. Some aspects of the ecology of the Thames Estuary in relation to pollution. PhD thesis, University of London

Huddart, T. and Arthur, D.R. 1971a. Shrimps and whitebait in the polluted Thames Estuary *International Journal of Environmental studies* **2,** pg. 21-23

Huddart, T. and Arthur, D.R. 1971b. Lampreys and teleosts fish, other than whitebait, in the polluted Thames estuary. *International Journal of Environmental Studies* **2,** pg.143-152

Huddart, T., and Arthur, D.R. 1971c. Shrimps in relation to Oxygen depletion and its Ecological significance in a polluted estuary. *Environmental pollution* **2,** pg. 13-35

Hutchinson, S. and Hawkins, L.E. 1993. The Migration and Growth of 0-group Flounders *Platichthys flesus* in Mixohaline conditions. *Journal of Fish. Biology* **43,** pg. 325-328

Hutchinson, S. and Hawkins, L.E. 1993. The Ecology of Smelt *Osmerus eperlanus* in The River Thames and the River Cray (Unpublished PhD). University of London

Hughes, R.M. 1985. Use of watershed characteristics to select control streams for estimating effect of metal mining wastes on extensively disturbed streams. *Environmental Management* **9,** pg. 253-262

Hynes, H.B.N. 1960. The Biology of Polluted Water. Pg. 131-133. Liverpool University Press, UK

Hyslop, E.V. 1980. Stomachs contents analysis – a review of methods and their application. *Journal of Fish Biology* 50, pg. 324–340.

Jarrah, Y.A. 1992. The biology of the flounder, Platichthys flesus in the Thames, a polluted estuary. PhD thesis. University of London

Jobling, M. 1995. Environmental Biology of Fishes: Human Impacts on aquatic Environments (Fresh water acidification). pg. 430. Springer

Jones, E. 1993. Map of South Thames Region based upon 1/100000 ordnance survey map of Great Britain, prepared for the Environment Agency. Environment Agency

Kartar, B.S. 1977. The ecology of flounders, Platichthys flesus, and other major species in the Severn Estuary and the Bristol Channel. PhD Thesis. University of Bath

Kennish, M.J. 1990. The ecology of estuaries. Boston Press

Kim, J., Mueller, and Charles, W. 1978. Introduction to factor analysis: What it is and how to do it. Newbury Park, CA: Sage Publications.

Kinniburgh, J. 1998. Physical and chemical characteristics of The Thames Estuary. In A Rehabilitated Estuarine Ecosystem; The environment and ecology of the Thames Estuary (Ed. Attrill, M. J.) Kluwer Academic Publishers pg. 27-48

Kovalek, W.P. 1979. Day-night changes in stream benthos density in relation to current to current velocity. *Hydrobiologie*. 87, pg1-18

Larsonneur, C. 1994. The Bay of Mont-Saint-Michel: A sedimentation model in a temperate macrotidal environment, *Senckenbergiana maritima*, 24, pg. 3-63.

Lebart, L., Morineou, A and Warwick, K. M. 1984. Multivariate Descriptive Statistical Analysis: Correspondence Analysis and Related Techniques for Large Matrices. John Wiley and Sons

Leeming, D. 1997. A biological survey of drainage dykes at Crayford Marshes. Environment Agency (Unpublished report)

Lithgoe G., and Lithgoe J. 1971. Fishes of the Sea. The Coastal Waters of the British Isles, Northern Europe and the Mediterranean . Blandford, pg. 54

Lorenz, M.O. (1905). Methods of measuring the concentration of wealth. *Publications of the American Statisical Association*. 9, pg. 209-219.

McIvor, C.C., and Odum, W.E. 1988. Food, predation risk, and microhabitat selection in a marsh fish assemblage. *Ecology*. 69, pg. 1341-1351.

Mackay, W.C., Ash G.R. and Norris H.J. (eds.). 1990. Fish Ageing Methods for Alberta. R.L. & L. Environmental Services Ltd. in assoc. with Alberta Fish and Wildl. Div. and Univ. of Alberta, Edmonton. pg. 113.

MacLellan, S.E. 1987. Guide for sampling structures used in age determination of Pacific salmon. Department of Fisheries and Oceans. Ministry of Sustainable Resource Management. Government of British Columbia.

Maitland, P.S. and Campbell, R.N 1992. Freshwater fishes. Harper Collins. Lodon

Mann, K.H. 1972. Macrophyte production and detritus food chains in coastal water. *Mem. 1st Ita. Idrobiol.*, 29, pg. 353-383

Mann, R.H.K. 1995. Natural Factors Influencing Recruitment Success in Coarse Fish Populations. *Natural Environment Research Council, Institute of Freshwater Ecology Huntindon, UK. In:* Harper, D. M. and Ferguson, A. J. D. Ferguson (1995) (Eds.) John Wiley and Sons Ltd. pg. 339-348

Mardia, K.V., Kent J.H. and Bibby J.M. 1979. Multivariate analysis. Academic Press. London pg. 521

Matthews, W.J., 1998. *Patterns in freshwater fish ecology.* Chapman and Hall

Miltner, R.J., Ross, S.W., and Posey, M.H.. 1995. Influence of food and predation on the depth distribution of juvenile spot (Leiostomus xanthurus) in tidal nurseries. *Canadaean Journal of Fishery and Aquatic Science.* 52, pg. 971-982.

Minitab Inc 2000. Minitab Statistical Software for Windows
Minitab Incorporated

Mitsch, K. and Gosselink, J. 1986. Wetlands. Van Nostrand Reinhold Co., NY
pg. 539

Morse, J.C., Chapin, J.W., Herlong, D.D. and Harvey, R. S. 1980. Aquatic insects of Upper Three Runs Creek, Savannah River Plant, South Carolina. Others other than Diptera. *Journal of the Georgia Entomological Society* 15, pg. 73-101

Moore, J.W. and Moore, I.A 1976. The basis of food selection in flounders, Platichthys flesus in the Severn Estuary. *Journal of Fishery Biology* 9, pg. 139-156

Muller, K. 1974. Investigation on the organic drift in North Swedish streams. *Rep. Inst. Freshwat. Res. Drottningholm* 35, pg. 133-148

Myers, B. 1988. A report of ten weeks work with Thames Water Authority Metropolitan Fisheries Offices; River Thames Upper Tideway Fry Survey 1988. MSc Aquatic Resources Management Report, Kings College London

Naismith, I.A. and Knight, B. 1988. Migration of elvers and juvenile European eels, *Anguilla anguilla* in the River Thames. *Journal of Fish Biology* **33**(A) pg. 161-175

Naismith, A.I. and Knights, B. 1993. The distribution, density and growth of European eel, *Anguilla anguilla*, in the freshwater catchment of the river Thames. *Journal of Fish Biology* 42(2), pg. 217-226

Naismith, I.A. and Knight, B. 1994. Fyke netting and coarse fisheries in Lowland Britain. Practical advice for fisheries owners and managers. *Fisheries management and ecology,* 4 issue 4 pg. 237-247

Neilsen, J.D. and G.H. Geen. 1981. Method for preparing otoliths for microstructure examination. Prog. Fish-Cult. **43**, pg. 90-91.

Nixon, S.W. 1980. Between coastal Marshes and coastal waters – A Review of twenty years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. In Hamilton, P. and McDonald, K. (Eds.) Estuarine and wetland processes. Plenum New York

Nixon, S.W. 1982. Nutrient Dynamics, Primary Production and Fishery yields of Lagoons. In Lasserre, P. and Postma H. (Ed), Coastal Lagoons. *Oceanologica Acta.* **5**, pg.357-371

Panfili, J. and Ximenes M.C. 1992. Measurements on ground or sectioned otoliths: Possibilities of bias. Journal of Fish Biology **41** (2), pg. 201-207.

Panfili, J. and. Ximenes M.C, 1994. Age and growth estimation of the European eel (*Anguilla anguilla* L.) in continental waters: Methodology, validation, application in Mediterranean area and comparisons in Europe. Bulletin Francais de la Peche et de la Pisciculture: pg. 44-66. Vol. 335

Panfilli, J., Ximenes, M.C. and Crivelli, A.J. 1994. Sources of variation in growth of the European eel, *Anguilla anguilla* estimated from otoliths. *Canadian Journal of Fishery and Aquatic Science.* **51**, pg. 506-515.

Parson, J.N. 1978. A study of the ecology of the flounder, *Platichthys flesus*, in the Dee Estuary. PhD thesis. University of Salford

Pivnicka, K. and Cerny, K. 1998. Illustrated book of fishes. Caxton Edition

Poole, W.R. and Reynolds, J.D., 1996. Age and growth of yellow eel, *Anguilla anguilla* (L.), determined by two different methods. *Ecology of Freshwater Fish* **5**, pg. 86-95.

Power, M., Attrill, M.J. and Thomas, R.M (2000). Temporal abundance patterns and growth of juvenile Clupeidae (herring and sprat) from the Thames estuary 1977-1992. J. *Fishery Biology.* **56**, pg. 1408-1426.

Power, M., Attrill, M.J. and Thomas, R.M. 2002. Environmental influences on the long-term fluctuations in the abundance of gadoid species during estuarine residency. *J. Sea Research* **47**, pg. 185-194.

Ramoeli, P. 1994. Water Quality Survey of the Dartford Creek. MSc Thesis University of London

Redeke, H.C. 1922. Zur Biologic der niederlandischen Brackwassertypen (Ein Beitrag zur regionalen Limnologie) *Bijdragen tot de Dierkunde* **22,** pg. 329-335

Rees, H.L. and Dare, P.T. 1993. Sources of mortality and associated life-cycle traits of selected benthic species: a review. *Fisheries Research Data Report* Number 33.

Remane, A. and Schlieper 1971. Biology of Brackish water. Wiley and Sons. New York pg. 372

Richardson, J.S. 1993. Limits to productivity in streams: evidence from studies of macroinvertebrates. *Can Spec. Publ. Fish. Aquat. Sci.* **118,** pg. 9-15

Rogers, S.I., Millner, R.S. and Mead, T.A. (1998). The distribution and abundance of young fish on the east and south coast of England (1981 to 1997). *Centre for Environment, Fisheries and Aquaculture Science.* Science series technical report Number 108

Royal Docks Management Authority 2004. Oceanography of the Royal Dock Basins. *http//www.rodma.co.uk/oceanography.htm*

Salthaug, A. 2001. Dynamic age-length keys. *Fishery Bulletin* **101** (2), pg. 451-456

Schafer, W. 1972. Ecology and Paleoecology of Marine Environments, 568. University of Chicago Press, Chicago.

Schnute, J., and D. Fournier. 1980. A new approach to length-frequency analysis: growt structure. *Can. J. Fish. Aquat. Sci.* **37,** pg. 1337-1351.

Schoener, T.W. 1970. Non-synchronous spatial overlap of lizards in patchy habitats. Ecology **51,** pg. 408-418

Sedgwick, R. and Arthur, D.R 1976. A natural pollution experiment: the effect of sewage strike on the fauna of the Thames Estuary. *Experimental Pollution* **11** (2) pg. 137-160

Sedgwick, R.W. 1978. Some aspects of the ecology and physiology of nekton in the Thames Estuary, with special reference to the shrimp, *Crangon vulgaris.* PhD thesis University of London.

Shannon, C. E., & Weaver, W. 1949. The mathematical theory of communication. Urbana IL: University of Illinois Press.

Stark, J.D. 1998: SQMCI: A biotic index for freshwater macroinvertebrate coded abundance data. *New Zealand Journal of Marine and Freshwater Research* **32**, pg. 55-66.

Summers, R.W. 1979. Life cycle and population ecology of the flounder, *Platichthys flesus* in the Ythan Estuary, Scotland. *Journal of Natural History* **13**, pg. 703-723

Summers, R.W. 1980. The diet and feeding behaviour of the flounder, *Platichthys flesus* in the Ythan Estuary, Aberdeenshire, Scotland. *Estuarine, Coastal Marine Science* **11**, pg. 217-232

Surber, E.W. 1937. Rainbow trout and bottom fauna production in one mile of stream. Tansaction of the American Fisheries society **66,** pg. 193-202.

Timm, N.H. 2002. Applied Multivariate Statistics. Springer Texts in Statistics

Tinsley, D. 1998. The Thames estuary: a history of the impact of humans on the environment and description of the current approach to environmental management. In *A Rehabilitated Estuarine Ecosystem; The environment and ecology of the Thames Estuary (Ed. Attrill, M. J.) Kluwer Academic Publishers* pg.1-25

Thames Estuary Benthic Research Group, 1997. Thames foreshore macroinvertebrate survey technical report. Unpublished report prepared by Thomas M. Environment Agency, Apollo Court, St. Alban Road West Hertfordshire. AL10 9EX

Thomas, M. 1998. Temporal changes in the movements and abundance of Thames estuary Fish population. *In*: A Rehabilitated Estuarine Ecosystem; The environment and ecology of the Thames Estuary (Ed. Attrill, M. J.) Kluwer Academic Publishers pg. 115-138

Thompson, R. M. and Townsend, C. R. 2000. Is resolution the solution? : The effect of taxonomic resolution on the calculated properties of three stream food webs. Freshwater biology 44(3), pg. 413-422

Thorne, R., Williams, W.P. 1997. The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. *Freshwater Biology* **37,** pg. 671-686

Turner, W.R. and Johnson, G.N. 1973. Distribution and Relative Abundance of Fishes in Newport River, North Carolina . NOAA Technical Report,
Washington, NMFS **666,** pg. 23

Valiela, I., 1984. Marine ecological processes. Springer-Verlag, New York 546, p652-656

Vennote, R.L., Minshall, K.W. Cummins, Sedell, J.R. and Cushing C.E. 1980. The river continuum concept. *The Canadian Journal of Fisheries and Aquatic Sciences* **37,** pg. 130-137

Wallace Jr., R. K., 1981. An assessment of diet-overlap indexes. *Trans. Am. Fish. Soc.,* **110,** pg. 72-76.

Ward, J.V. and Stanford, J.A. 1991. Benthic faunal pattern along the longitudinal gradient of a rocky mountain river system. *Verhandlungen der Internationalen Vereinigung fur Theoretische und Angewandte Limnologie* 24, pg. 3087-3094

Warren, P.J. & Sheldon, R.W. 1967. Feeding and migration patterns of the Pink Shrimp *Pandalus montagui*, in the estuary of the River Crouch, England, *Journal of the Fisheries Research Board of Canada*, 24, pg. 569-580.

Warren, P.J. 1973. The fishery for the Pink Shrimp *Pandalus Montagui* in the Wash. Ministry of Agriculture, Fisheries and Food, Lowestoft, Laboratory Leaflet (New Series) 28, pg. 46.

Waters, T.F. 1972. The drift of stream insects. *Annual Review of Entomology*. **17,** pg. 253-272

Wetzel, R.G., Rich, P.H., Miller, M.C. and Allen, H.L. 1972. Metabolism of dissolved and particulate detrital carbon in a temperate hard water lake, In Hopton, J. and Melchorri-Santalini, U. (Eds.) Detritus and its Role in aquatic ecosystem. *Memoir Inst. Italiano Idriobiol.* 29, pg. 185

Wheeler, A. 1969a. Fish life and pollution in the lower Thames: A review and preliminary report. Biological Conservation 2(1), pg. 25-30

Wheeler, A. 1969b. The Fish of the British Isles and North West Europe. McMillan London

Wheeler, A. 1979. The Tidal Thames. The History of a River and its Fishes Routledge and Kegan Paul

Williams, D. D. and Williams N. E. 1998. Seasonal variation, export dynamics and consumption of freshwater invertebrates in an estuarine environment. *Estuarine Coastal and Shelf Science* 46, pg. 393-410

Williams, R.J., White, C., Harrow, M.L. and Neal, C. 2000. Temporal and small-scale spatial variations of dissolved oxygen in the Rivers Thames, Pang and Kennet, UK. Science of The Total Environment pp251-252 and pg. 497-510

Winemiller, K.O. 1989. Ontogenetic diet shifts and resource partitioning among piscivorous fishes in Venezuelan Llanos. *Environmental Biology of Fish,* 26. pg. 1043-1061

Winemiller, K.O. and Kelso-Winemiller, L.C. 1996. Comparative ecology of catfisheses of the upper Zambesi river flood plain. *Journal of Fisheries Biology* 49, pg. 177-199

Winterbourn, M.J. 1985: Sampling stream invertebrates In: Pridmore R. D. & Cooper A. B. eds. Biological monitoring of freshwaters: proceedings of a seminar. *Water and soil miscellaneous publication* no. 83. National Water and Soil Conservation Authority, Wellington. pg. 241-258.

Wolff, W.J. 1973. The estuary as a habitat. An analysis of the data on the soft-bottom macrofauna of the estuarine area of the rivers Rhine, Meuse, and Scheldt. Museum of Natural History. Leiden, The Netherlands, *Zoological Treatise* **126**, pg. 242

Wolff, W.J., Manders, M. A. and Sandee 1981. Tidal migration of plaice and flounder as a feeding strategy. In "feeding and survival strategies of estuarine organisms" (N. V. Jones and Wolff ed.) pg. 159-171 Plenum Press London

Wood, L.B. 1980. The rehabilitation of the tidal river Thames. Public Health Engineer 8(3), pg. 112-120

Wood, L.B. 1982 Restoration of the tidal River Thames. Adam Hilger Ltd, Bristol, pg. 195

Yanez-Arancibia, A. 1986. Recruitment Process in tropical coastal demersal communities. Pro. IOC-FAO-UNISCO workshop. OSLR/IREP Project. UNESCO. Paris 44

Appendix 4: Monthly 0+ and 1+ fish populations

Table 1 monthly 0+ fish population at Teddington site from May 2001 to April 2002 captured with a knotless seine net

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
roach	12	300	990	1860	566	210	37	357	6	80	1062	0	5480	82.8
flounder	2	60	0	0	1	3	0	0	0	0	0	0	66	1.0
3-s'stickleback	0	2	0	0	0	0	0	0	0	0	19	20	41	0.6
dace	0	0	0	31	1	0	0	0	40	738	1	0	811	12.3
sea bass	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
bream	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
common goby	0	0	0	0	0	0	4	0	0	0	2	0	6	0.1
smelt	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
sand smelt	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
perch	0	192	0	0	0	0	0	0	0	0	0	0	192	2.9
chub	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
sand goby	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
10-s'stickleback	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
15-s'stickleback	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
eel	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
place	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
grey mullet	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
barbel	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
dab	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
bleak	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
gudgeon	0	0	18	0	0	0	0	0	0	0	0	0	18	0.3
minnow	4	0	0	0	0	0	0	0	0	0	0	0	4	0.1
bullhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
herring	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
whiting	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	18	554	1008	1891	568	213	41	357	46	818	1084	20	6618	100.0

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 2 Monthly 1+ fish populations at Teddington site from May 2001 to April 2002 captured with 4mm knotless seine net

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	38	19	108	12	17	1190	20	643	134	820	18	27	3046	76
FL	0	0	0	0	0	1	5	3	3	9	8	2	31	0.8
3SB	3	2	0	0	0	0	0	0	0	4	0	0	9	0.2
DA	1	0	55	10	51	4	5	66	6	102	4	28	332	8.3
SBA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BR	0	0	0	20	0	2	0	21	0	0	0	0	43	1.1
CGB	0	0	0	0	0	0	7	0	0	0	4	0	11	0.3
SM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PER	0	0	9	24	2	0	5	15	0	0	0	1	56	1.4
CHB	0	0	0	21	26	0	0	39	0	0	0	0	86	2.2
SGB	0	0	0	0	2	0	0	0	0	0	0	0	2	0.1
10SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLK	3	3	3	3	0	0	0	0	0	0	3	3	18	0.5
GU	6	6	230	36	8	1	9	18	0	0	4	0	318	8
MI	3	7	7	0	0	0	0	0	1	0	0	2	20	0.5
BH	0	0	0	0	0	0	0	0	1	0	0	10	11	0.3
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	54	37	412	126	106	1198	51	805	145	935	41	73	3983	100
%	1.36	0.93	10.3	3.16	2.66	30.1	1.3	20	3.6	23	1.03	1.83	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 3Monthly 0+ fish populations at Hammersmith site in the low salinity Zone 1 of the Thames Estuary from May 2001 to April 2002 captured with a 4mm seine at low tide

Species	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	0	0	117	1631	1287	153	29	21	0	0	3	0	3241	41
FL	3162	845	180	32	69	0	0	0	0	0	0	0	4288	55
3SB	0	21	50	141	4	39	2	8	1	0	0	0	266	3.4
DA	0	5	0	3	0	0	0	0	0	0	0	0	8	0.1
SBA	0	0	5	0	0	0	0	0	0	0	0	0	5	0.1
BR	0	1	0	1	0	0	0	0	0	0	0	0	2	0
CGB	0	0	0	15	0	0	0	0	0	0	0	0	15	0.2
SM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	0	0	13	0	0	0	0	0	13	0.2
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLK	0	0	0	9	0	0	0	0	0	0	0	0	9	0.1
GU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0	1	0	0	1	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	3162	872	352	1832	1360	192	44	29	1	1	3	0	7848	100
%	40	11	4	23	17	2	1	0	0	0	0	0	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 4 Monthly 1+ fish populations at Hammersmith site in Zone 1 of the Thames Estuary from May 2001 to April 2002 captured by a 4mm seine at low tide

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	9	62	53	95	903	125	1	91	0	0	24	28	1391	71
FL	0	0	0	9	1	0	3	36	0	0	0	6	55	2.8
3SB	4	0	0	8	0	8	11	6	2	0	0	0	39	2
DA	31	12	0	1	0	4	2	4	0	0	270	30	354	18
SBA	0	0	0	0	0	1	0	0	0	0	0	0	1	0.1
BR	0	0	1	5	1	5	0	2	0	0	3	0	17	0.9
CGB	0	0	0	10	6	11	8	6	7	4	0	0	52	2.6
SM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSM	0	0	0	0	0	6	3	0	0	0	0	0	9	0.5
PER	0	0	5	0	0	1	0	5	0	0	1	0	12	0.6
CHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	1	2	0	0	0	0	0	0	0	3	0.2
PLC	0	0	0	0	10	0	0	0	0	0	0	0	10	0.5
GMU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	10	0	0	0	0	0	0	0	10	0.5
DB	0	0	0	15	0	0	0	0	0	0	0	0	15	0.8
BLK	0	0	0	0	0	0	0	0	0	0	1	0	1	0.1
GU	0	0	0	0	0	0	0	0	0	2	0	0	2	0.1
MI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	44	74	59	144	933	161	28	150	9	6	299	64	1971	100
%	2	4	3	7	47	8	1	8	0	0	15	3	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 5 Monthly populations of 0+ fish at Battersea in the transition between the low salinity Zone 1 and the brackish water Zone 2 of the Thames Estuary from May 2001 to April 2002 captured with a 4mm seine net at low tide

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	0	1722	69	473	48	27	0	0	0	0	125	0	2464	31
FL	2214	458	110	29	19	8	11	1	0	0	0	2170	5020	64
3SB	0	40	38	32	4	2	0	0	0	0	0	0	116	1.5
DA	0	0	78	14	0	0	0	0	0	0	0	0	92	1.2
SBA		40	40	40	0	1	0	0	0	0	0	0	121	1.5
BR	0	0	5	1	0	0	0	0	0	0	0	0	6	0.1
CGB	0	0	13	29	9	8	3	4	0	1	0	0	67	0.8
SM	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSM	0	0	0	7	2	0	0	0	0	0	0	0	9	0.1
PER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	5	0	0	0	0	0	0	0	5	0.1
9SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	2214	2260	353	625	87	46	14	5	0	1	125	2170	7900	100
%	28	28.6	4.47	7.91	1.1	0.58	0.2	0.1	0	0	1.58	27.5	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 6 Monthly populations of 1+ fish at Battersea in the transition between the low salinity Zone 1 and the brackish water Zone 2 of the Thames Estuary from May 2001 to April 2002 captured with a 4mm seine net at low tide

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	12	0	1	7	7	66	1	9	0	0	83	1	187	32
FL	0	0	9	4	26	11	19	22	0	3	9	0	103	18
3SB	4	0	2	2	1	1	0	3	0	0	0	0	13	2.2
DA	0	0	0	20	2	2	0	0	0	0	5	0	29	5
SBA	0	0	0	0	2	59	0	0	0	0	0	0	61	10
BR	0	0	0	9	5	5	0	2	0	0	3	0	24	4.1
CGB	0	0	0	0	12	2	4	7	0	9	0	0	34	5.8
SM	0	0	0	3	0	2	0	0	0	0	0	0	5	0.9
SSM	0	0	0	0	45	20	0	0	0	0	0	0	65	11
PER	0	0	0	2	4	0	0	0	0	0	4	1	11	1.9
CHB	0	0	0	2	4	0	0	0	0	0	0	45	51	8.7
SGB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	1	0	0	0	0	0	0	1	0.2
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	16	0	12	49	108	169	24	43	0	12	104	47	584	100
%	2.74	0	2.05	8.39	18.5	28.9	4.1	7.4	0	2.1	17.8	8.05	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 7 Monthly 0+ fish populations at Greenwich site in Zone 2 of the Thames Estuary from May 2001 to April 2002 captured by a 4mm knotless seine net at low tide

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	16	26	0	0	0	0	0	0	0	0	0	0	42	1.5
FL	689	187	22	0	0	0		0	0	0	0	0	898	32
3SB	39	77	27	270	3	0	0	0	0	0	0	0	416	15
DA	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SBA	0	0	240	350	0	0	0	0	0	0	0	0	590	21
BR	0	0	3	0	0	9	0	0	0	0	0	0	12	0.4
CGB	0	0	0	270	15	0	0	0	0	0	0	0	285	10
SM	0	0	7	438	0	0	0	0	0	0	0	0	445	16
SSM	0	0	0	0	10	0	0	0	0	0	0	0	10	0.4
PER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9SB	0	0	2	0	0	0	0	0	0	0	0	0	2	0.1
15SB	0	0	0	0	32	0	0	0	0	0	0	0	32	1.1
EL	0	3	0	0	0	0	0	0	0	0	0	0	3	0.1
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	16	23	0	2	6	4	0	0	51	1.8
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BLK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	744	293	301	1328	76	32	0	2	6	4	0	0	2786	100
%	26.7	10.5	10.8	47.7	2.73	1.15	0	0.1	0.2	0.1	0	0	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 8 Monthly 1+ fish populations at Greenwich site in Zone 2 of the Thames Estuary from May 2001 to April 2002 captured by a 4mm knotless seine net at low tide

Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	7	17	2	32	95	48	6	16	28	51	6	2	310	17
FL	19	35	8	32	64	21	18	14	5	65	7	2	290	15
3SB	0	0	3	0	0	0	0	0	0	0	0	0	3	0.2
DA	2	4	0	0	3	2	2	1	0	5	0	0	19	1
SBA	0	0	0	10	22	99	140	1	0	0	0	0	272	14
BR	3	5	1		11	352	51	10	0	0	0	0	433	23
CGB	0	0	0	0	0	0	0	4	0	8	0	0	12	0.6
SM	1	3	0	0	118	46	0	8	0	0	0	0	176	9.4
SSM	3	0	0	0	108	46	0	0	6	0	22	0	185	9.9
PER	0	0	0	3	0	0	0	0	6	0	0	0	9	0.5
CHB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0	0	0	3	2	0	5	0.3
10SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	1	0	0	0	0	0	1	0.1
PLC	0	0	1	2	6	9	5	8	2	8	0	0	41	2.2
GMU	0	0	4	0	0	0	0	0	0	0	0	0	4	0.2
BAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLC	0	0	1	2	6	9	5	8	2	8	0	0	41	2.2
DB	0	0	0	9	0	2	18	21	13	8	4	1	76	4
BLK	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	35	64	20	90	433	634	246	91	62	156	41	5	1877	100
%	1.86	3.41	1.07	4.79	23.1	33.8	13	4.8	3.3	8.3	2.18	0.27	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab;PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 9 **Monthly 0+ fish populations at Belvedere site in Zone 2 of the Thames Estuary from May 2001 to September 2002 captured by a 4mm seine net at low tide**

Month	May	Jun	Jul	Aug	Sep	Total	%
RO	14	0	0	9	0	23	0.9
FL	1002	55	40	12	2	1111	45
3SB	0	35	0	192	0	227	9.1
DA	0	0	0	0	0	0	0
SBA	0	0	180	174	8	362	15
BR	0	0	0	0	0	0	0
CGB	0	0	0	5	24	29	1.2
SM	702	0	0	0	22	724	29
SSM	0	0	0	0	0	0	0
PER	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0
9SB	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0
GMU	8	0	8	0	0	16	0.6
BAR	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0
BLK	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0
Total	1726	90	228	392	56	2492	100
%	69.3	3.61	9.15	15.7	2.25	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice; SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 10 **Monthly 1+ fish populations at Belvedere site in Zone 2 of the Thames Estuary from May 2000 to September 2000 captured by a 4mm knotless seine net at low tide**

Month	May	Jun	Jul	Aug	Sep	Total	%
RO	16	0	2	8	0	26	5
FL	0	0	0	5	30	35	6.7
3SB	4	0	8	0	8	20	3.8
DA	2	2	2	2	0	8	1.5
SBA	0	0	0	6	32	38	7.2
BR	3	3	3	3	0	12	2.3
CGB	0	0	0	67	0	67	13
SM	1	0	21	108	5	135	26
SSM	1	14	0	58	0	73	14
PER	0	0	0	2	0	2	0.4
CHB	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0
10SB	0	0	2	0	8	10	1.9
15SB	0	0	0	0	0	0	0
EL	12	0	5	0	0	17	3.2
PLC	1	2	6	9	5	23	4.4
GMU	0	0	0	0	0	0	0
BAR	5	0	0	0	0	5	1
PLC	1	2	6	9	5	23	4.4
DB	0	9	0	2	8	19	3.6
BLK	0	0	0	12	0	12	2.3
GU	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0
Total	46	32	55	291	101	525	100
%	8.76	6.1	10.5	55.4	19.2	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 11 **Monthly 0+ fish populations at Grays site in Zone 2 of the Thames Estuary from May 2000 to September 2000 captured by a 4mm knotless seine net at low tide**

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	0	0	0	0	0	0	0	0	0
FL	0	0	0	0	0	0	0	0	0
3SB	0	0	0	0	0	0	0	0	0
DA	0	0	0	0	0	0	0	0	0
SBA	0	0	0	0	0	0	0	0	0
BR	0	0	0	0	0	0	0	0	0
CGB	0	0	0	0	0	0	0	0	0
SM	0	0	0	0	0	0	0	0	0
SSM	0	0	0	0	0	0	0	0	0
PER	0	0	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	0	0	0	0	0
10SB	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0
GMU	0	0	0	0	0	0	0	0	0
BAR	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0
DB	0	0	0	0	0	0	0	0	0
BLK	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0
HER	0	0	0	0	0	0	0	0	0
WH	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	0	0	0	0	0
%	0	0	0	0	0	0	0	0	0

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Table 12 **Monthly 1+ fish populations at Grays site in Zone 2 of the Thames Estuary from October 2000 to April 2001 captured by a 4mm knotless seine net at low tide**

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total	%
RO	0	0	0	0	0	0	0	0	0
FL	21	6	57	19	52	10	7	172	22
3SB	0	0	0	0	0	6	0	6	0.8
DA	0	0	0	0	0	0	0	0	0
SBA	59	15	64	61	47	4	26	276	36
BR	0	0	0	0	0	0	0	0	0
CGB	3	0	0	0	0	0	0	3	0.4
SM	0	0	0	0	4	0	3	7	0.9
SSM	0	0	0	0	0	0	0	0	0
PER	0	0	0	0	0	0	0	0	0
CHB	0	0	0	0	0	0	0	0	0
SGB	0	0	0	0	6	5	0	11	1.4
10SB	0	0	0	0	0	0	0	0	0
15SB	0	0	0	0	0	0	0	0	0
EL	0	0	0	0	0	0	0	0	0
PLC	0	0	0	0	0	0	0	0	0
GMU	0	8	0	0	0	0	0	8	1
BAR	0	0	0	0	0	0	0	0	0
PLC	41	22	6	19	21	42	8	159	21
DB	12	34	8	4	8	8	18	92	12
BLK	0	0	0	0	0	0	0	0	0
GU	0	0	0	0	0	0	0	0	0
MI	0	0	0	0	0	0	0	0	0
BH	0	0	0	0	0	0	0	0	0
HER	0	0	24	6	1	0	0	31	4
WH	0	0	0	0	3	0	0	3	0.4
Total	136	85	159	109	142	75	62	768	100
%	17.7	11.1	20.7	14.2	18.5	9.77	8.1	100	

Ro = roach; FL = flounder; 3SB = 3-spined stickleback; DA = dace; SBA = sea bass; SM = smelt BR = bream; CGB = common goby; Per = perch; CHB = chub; SSM = sand smelt; 15SB = 15- spine Stickleback; 10SB = 10 - spined stickleback; EL = eel; GMU = grey mullet; BLK = Bleak; BAR = Barbel; DB = dab; PLC = plaice. SGB = sand goby; BLK = bleak; GU = gudgeon; MI = minnow; BH = bullhead; HER = herring; WH = whiting;

Appendix 5: Diet-species matrix

Table 1 Zone 1 summer 2001- 0+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and % Frequency of occurrence of the food group in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	8	1	0	5	0	0	1	0	0	0	0	0
Crangonids	6	0	0	0	0	6	8	0	0	10	9	0
Gammarids	10	10	9	8	10	10	10	10	0	8	10	0
Amphipods	10	7	7	10	9	0	1	0	0	10	10	0
Copepods	2	0	0	0	8	0	10	0	0	7	0	0
Isopods	8	0	0	2	1	4	8	0	0	6	4	0
Cyprid larvae	2	2	4	8	2	4	6	6	2	1	3	3
Terestrial insects	0	2	1	0	0	0	0	0	0	0	0	0
Detritus	7	7	6	8	10	10	8	10	8	0	0	10
Water weeds	0	5	2	0	0	0	3	0	0	0	0	0
Algae	2	7	2	0	0	0	0	0	0	0	0	0
Silt	0	0	0	9	7	10	0	0	0	0	0	0
Oligochaetes	3	0	0	10	9	8	10	10	0	0	0	10
Chironomids	3	0	8	0	0	4	0	10	0	0	0	0
Polychaetes	0	0	0	0	0	7	0	7	0	6	0	4
Gastropods	7	0	0	0	0	1	0	3	4	0	0	0
Perch/fry	0	0	0	0	0	0	0	0	0	0	2	0
Smelt/fry	0	0	0	0	0	0	0	0	0	6	4	0
Bleak/fry	0	0	0	0	0	0	0	2	0	2	2	0
Roach/fry	10	0	0	0	0	6	0	0	5	1	1	0
Mullet/fry	5	0	0	0	0	0	0	0	0	4	6	0
Flounder/fry	0	0	0	0	0	2	0	0	0	0	1	0
Dace/fry	0	0	0	0	0	3	0	0	0	0	0	0
Goby/fry	3	0	0	0	0	0	0	0	0	0	0	0
Stickleback/fry	2	0	0	0	0	0	0	0	0	0	1	0
Bass/fry	0	0	0	0	0	0	0	0	0	3	0	0
Total	88	41	39	60	56	75	65	58	19	64	53	27
% crustaceans	52	49	51	55	54	32	68	28	11	66	68	11
% other	25	51	49	45	46	53	32	69	63	9	0	89
% Fish	23	0	0	0	0	15	0	3	26	25	32	0

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet

Table 2 Zone 2 summer 2001- 0+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and % Frequency of occurrence of the food group in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	8	7	6	6	10	0	0	2	0	6	6	4
Crangonids	0	0	0	0	0	5	0	8	0	0	0	0
Gammarids	7	0	6	3	0	9	9	10	5	8	10	0
Amphipods	8	9	7	7	0	9	0	10	5	10	10	0
Copepods	10	10	10	10	9	5	0	2	0	9	10	6
Isopods	5	0	2	2	3	7	6	8	0	7	8	0
Cyprid larvae	8	6	7	10	8	0	9	8	4	1	1	0
Terestrial insects	0	1	1	0	0	0	0	0	0	0	0	0
Detritus	3	10	0	3	9	0	9	7	0	0	0	10
Water weeds	0	0	0	0	0	0	0	0	0	0	0	0
Algae	0	0	0	0	0	0	0	0	0	0	0	0
Silt	0	0	0	0	0	0	0	9	0	0	0	9
Oligochaetes	8	9	7	8	10	10	9	9	9	0	0	0
Chironomids	6	7	3	7	8	10	7	8	4	0	0	0
Polychaetes	0	0	0	0	0	5	1	6	0	0	5	0
Gastropods	8	0	2	2	0	4	6	9	4	0	0	0
Perch/fry	0	0	0	0	0	0	0	0	0	0	0	0
Smelt fry	7	0	0	0	0	6	0	2	8	0	8	0
Bleak/fry	0	0	0	0	0	0	0	0	0	0	0	0
Roach/fry	0	0	0	0	0	0	0	0	0	0	0	0
Mullet/fry	0	0	0	0	0	0	0	0	0	0	0	0
Flounder/fry	0	0	0	0	0	0	0	0	0	0	0	0
Dace/fry	0	0	0	0	0	0	0	0	0	0	0	0
Goby/fry	0	0	0	0	0	0	0	0	0	0	0	0
Stickleback/fry	0	0	0	0	0	0	0	0	0	0	0	0
Bass/fry	0	0	0	0	0	0	0	0	0	0	0	0
Total	78	59	51	58	57	70	56	98	39	41	58	29
%Crustaceans	59	54	61	66	53	50	43	49	36	100	78	34
%other	32	46	39	34	47	41	57	49	44	0	9	66
%Fish	9	0	0	0	0	9	0	2	20	0	14	0

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet

Table 3 Zone 1 summer 2001- 1+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and % Frequency of occurrence of the food group in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	4	0	3	8	8	6	6	4	3	10	6	2
Crangonids	4	1	0	0	2	7	0	0	0	4	7	1
Gammarids	10	8	7	10	10	10	10	6	8	10	10	8
Amphipods	7	7	6	6	10	6	10	10	10	10	10	10
Copepods	3	6	0	2	8	8	8	10	8	8	8	0
Isopods	4	0	4	6	6	4	8	6	6	6	10	3
Cyprid larvae	6	4	3	10	8	6	8	6	4	8	8	1
Terestrial insects	6	10	10	1	6	6	6	0	0	0	0	1
Detritus	1	2	4	1	6	4	0	2	0	0	0	2
Water weeds	0	4	4	0	0	0	5	0	0	0	0	0
Algae	0	3	6	0	0	0	0	0	0	0	0	5
Silt	1	0	2	0	1	2	0	7	10	0	0	2
Oligochaetes	4	6	4	7	5	6	10	6	10	0	3	7
Chironomids	8	5	10	8	10	10	10	10	6	0	1	8
Polychaetes	1	0	0	0	0	0	0	1	0	0	0	4
Gastropods	2	0	6	4	6	3	4	10	6	0	0	10
Perch/fry	6	0	0	0	0	6	0	0	0	4	7	0
Smelt/fry	1	0	0	0	1	8	0	0	0	0	6	0
Bleak/fry	7	0	0	0	0	6	0	0	4	4	2	0
Roach/fry	10	0	0	0	0	10	0	0	0	10	10	0
Mullet/fry	0	0	0	0	0	1	0	0	0	0	6	0
Flounder/fry	10	0	0	0	0	10	0	0	5	10	9	0
Dace/fry	6	0	0	0	0	10	0	0	3	10	6	0
Goby/fry	3	0	0	0	1	4	0	2	2	10	3	0
Stickleback/fry	4	0	0	0	0	2	0	0	1	10	4	0
Bass/fry	0	0	0	0	0	10	0	0	0	10	4	0
Total	108	56	69	63	88	145	85	80	86	124	120	64
%Crustaceans	35	46	33	67	59	32	59	53	45	45	49	39
%Other	21	54	67	33	39	21	41	45	37	0	3	61
%Fish	44	0	0	0	2	46	0	3	17	55	48	0

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet

Table 4 Zone 2 summer 2001 - 1+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and % Frequency of occurrence of food groups in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	4	6	0	3	8	2	8	3	3	8	2	0
Crangonids	7	1	4	2	8	10	3	8	6	10	9	0
Gammarids	6	3	3	10	6	6	9	8	9	10	9	0
Amphipods	8	10	10	10	6	10	8	9	9	10	10	9
Copepods	9	8	8	8	5	7	9	2	5	10	5	0
Isopods	7	0	9	10	8	10	4	8	8	2	8	8
Cyprid larvae	1	6	4	10	10	10	10	8	4	1	1	6
Terestrial insects	0	3	0	2	0	1	0	0	0	0	0	0
Detritus	2	9	10	8	10	10	0	9	2	0	0	10
Water weeds	0	0	4	0	0	0	2	0	0	0	0	0
Algae	0	0	2	0	0	0	7	0	0	0	0	10
Silt	1	8	8	8	8	8	0	10	5	0	0	10
Oligochaetes	1	9	9	10	10	10	8	10	10	2	1	10
Chironomids	0	3	4	7	8	8	6	7	7	2	1	6
Polychaetes	1	6	6	6	8	9	2	9	3	1	2	8
Gastropods	0	3	8	1	6	6	8	9	8	0	0	7
Perch/fry	6	0	0	0	0	1	0	0	0	0	2	0
Smelt fry	6	0	0	0	0	6	3	8	7	8	9	6
Bleak/fry	8	0	0	0	0	2	0	0	0	0	1	0
Roach/fry	4	0	0	0	0	5	0	0	8	1	2	0
Mullet/fry	6	0	0	0	0	4	0	0	0	7	8	0
Flounder/fry	6	0	0	0	0	6	0	0	7	9	4	0
Dace/fry	7	0	0	0	0	4	0	0	0	2	2	0
Goby/fry	6	0	0	0	0	9	0	6	9	8	9	0
Stickleback/fry	7	0	0	0	0	4	0	0	2	2	6	0
Bass/fry	6	0	0	0	0	8	0	0	6	9	8	0
Total	109	75	89	95	101	156	87	114	118	102	99	90
% Crustaceans	39	45	43	56	50	35	59	41	37	50	44	26
% Other	4	55	57	44	50	33	38	47	30	5	4	68
% Fish	57	0	0	0	0	32	3	12	33	45	52	6

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet

Table 5 Zone 1 winter 2001 - 1+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and % Frequency of occurrence of food groups in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	10	10	10	8	8	6	10	4	3	10	6	2
Crangonids	4	1	0	0	2	7	0	3	0	10	9	1
Gammarids	10	10	10	10	10	10	10	9	8	10	10	8
Amphipods	7	7	6	6	10	6	10	10	10	10	10	10
Copepods	10	8	2	2	9	7	7	10	8	10	10	0
Isopods	8	0	4	5	7	10	9	7	4	5	10	3
Cyprid larvae	0	0	0	0	0	0	0	0	0	0	0	0
Terestrial insects	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	6	10	10	5	10	10	0	5	0	0	0	9
Water weeds	0	0	0	0	0	0	2	0	0	0	0	0
Algae	0	0	0	0	0	0	0	0	0	0	0	3
Silt	1	0	0	0	1	2	0	7	10	0	0	2
Oligochaetes	2	10	10	10	10	10	10	7	10	0	3	7
Chironomids	8	5	10	8	10	10	10	10	6	0	1	8
Polychaetes	1	0	0	0	0	0	0	1	0	0	0	4
Gastropods	2	0	6	4	6	3	4	10	6	0	0	10
Perch/fry	0	0	0	0	0	6	0	0	0	0	0	0
Smelt/fry	0	0	0	0	1	1	0	0	0	0	0	0
Bleak/fry	0	0	0	0	0	0	0	0	4	0	0	0
Roach/fry	0	0	0	0	0	10	0	0	0	0	0	0
Mullet/fry	0	0	0	0	0	10	0	0	0	0	0	0
Flounder/fry	0	0	0	0	0	0	0	0	5	0	0	0
Dace/fry	0	0	0	0	0	0	0	0	3	0	0	0
Goby/fry	0	0	0	0	1	0	0	2	2	0	0	0
Stickleback/fry	0	0	0	0	0	0	0	0	1	0	0	0
Bass/fry	0	0	0	0	0	0	0	0	0	0	0	0
Total	69	61	68	58	85	108	72	85	80	55	59	67
% crustaceans	71	59	47	53	54	43	64	51	41	100	93	36
% other	29	41	53	47	44	32	36	47	40	0	7	64
% Fish	0	0	0	0	2	25	0	2	19	0	0	0

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet

Table 6 Zone 2 winter 2001 - 1+ fish species-diet matrix. Number of fish (maximum 10) containing a particular food item and% Frequency of occurrence of food group in the diet

Food items	PER	DA	RO	CGB	GU	EEL	BR	FL	3SB	SM	SBA	MU
Branchiopods	10	10	10	10	10	2	10	2	10	10	6	1
Crangonids	10	0	0	0	4	10	2	3	0	10	10	0
Gammarids	10	5	10	2	10	10	10	10	2	10	10	4
Amphipods	10	10	10	10	10	10	10	10	10	10	10	1
Copepods	10	0	10	10	9	0	10	10	10	10	10	0
Isopods	2	0	0	1	7	10	9	0	2	10	10	0
Cyprid larvae	0	0	0	0	0	0	0	0	0	0	0	0
Terestrial insects	0	0	0	0	0	0	0	0	0	0	0	0
Detritus	6	10	10	10	10	10	0	10	0	0	0	10
Water weeds	0	0	0	0	0	0	0	0	0	0	0	0
Algae	0	0	0	0	0	0	0	0	0	0	0	0
Silt	0	0	0	0	10	10	0	10	10	0	0	10
Oligochaetes	0	10	10	10	10	2	10	10	10	0	1	10
Chironomids	0	0	0	0	0	0	0	0	0	0	0	0
Polychaetes	0	0	0	0	0	0	0	2	0	0	0	0
Gastropods	0	0	0	0	0	0	0	0	0	0	0	0
Perch/fry	0	0	0	0	0	0	0	0	0	0	0	0
Smelt/fry	0	0	0	0	0	0	0	0	0	0	0	0
Bleak/fry	0	0	0	0	0	0	0	0	0	0	0	0
Roach/fry	7	0	0	0	0	10	0	0	0	10	10	0
Mullet/fry	8	0	0	0	0	10	0	0	0	10	10	0
Flounder/fry	0	0	0	0	0	0	0	0	0	0	0	0
Dace/fry	2	0	0	0	0	0	0	0	0	0	0	0
Goby/fry	8	0	0	0	1	4	0	1	0	10	7	0
Stickleback/fry	0	0	0	0	0	2	0	0	0	0	0	0
Bass/fry	0	0	0	0	0	0	0	0	0	0	0	0
Total	83	45	60	53	81	90	61	68	54	90	84	36
% crustaceans	63	56	67	62	62	47	84	51	63	67	67	17
% other	7	44	33	38	37	24	16	47	37	0	1	83
% Fish	30	0	0	0	1	29	0	1	0	33	32	0

PER = perch; DA = dace; RO = roach; CGB = common goby; GU = gudgeon; EEL = eel; BR = bream; FL = flounder; 3SB = three-spined stickleback; SM = smelt; SBA = sea bass; MU = mullet